Pacific Marine Environmental Laboratory

Annual Report for FY 88
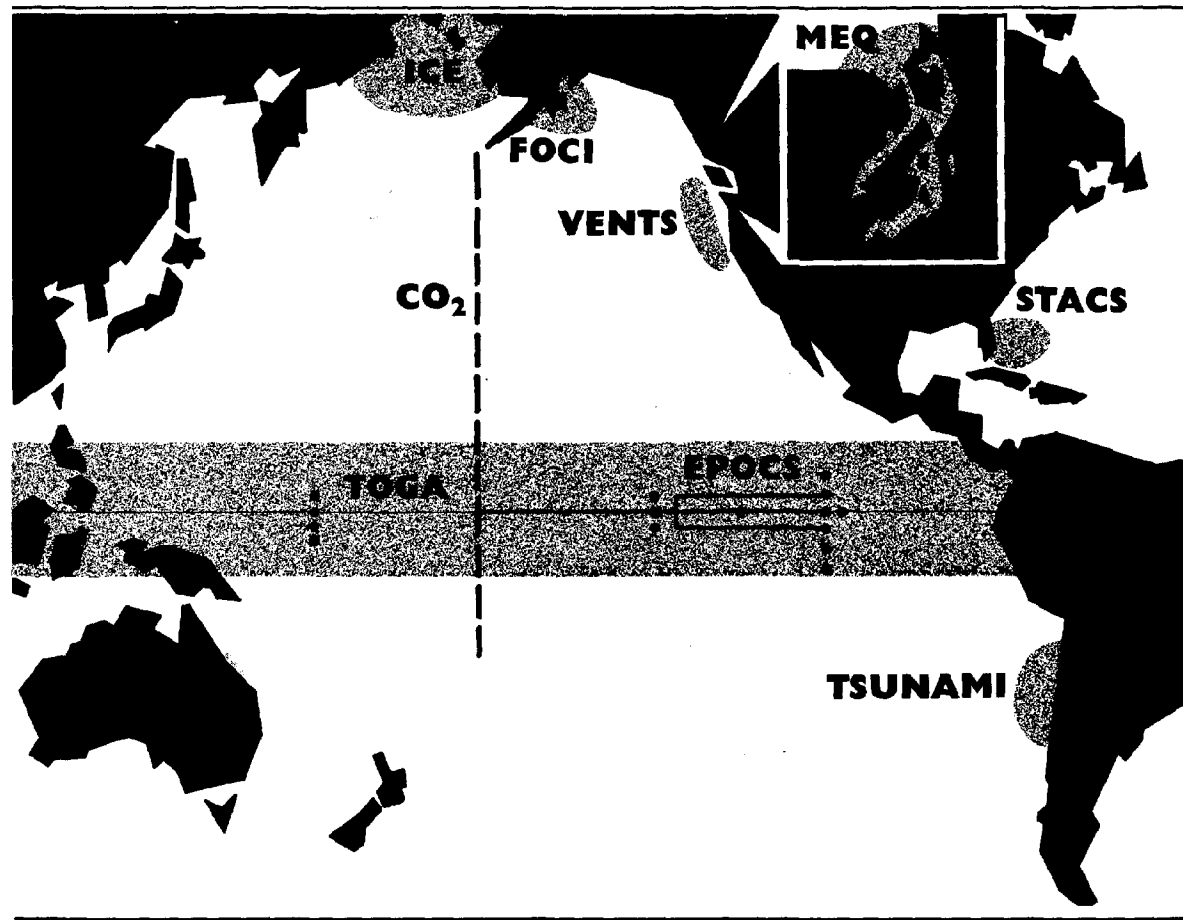
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PACIFIC MARINE ENVIRONMENTAL LABORATORY ANNUAL REPORT FISCAL YEAR 1988

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Pacific Marine Environmental Laboratory
7600 Sand Point Way NE
Seattle, WA 98115

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INTRODUCTION

E.N. Bernard, Director

The Pacific Marine Environmental Laboratory (PMEL) conducts interdisciplinary scientific investigations in oceanography, marine meteorology, and related subjects. Current PMEL programs focus on climate, marine observation and prediction, marine resources, and marine environmental assessment. Studies are conducted to define the forcing functions and the processes driving ocean circulation and the global climate system; to improve environmental forecasting capabilities and other supporting services for marine commerce and fisheries; and to improve our understanding of the complex physical and geochemical processes that determine the extent of human effect on the marine environment. The products of this research are environmental information and predictive models. These products are disseminated to the scientific community and public in the form of scientific papers, technical reports, and presentations at various scientific gatherings.

PMEL complements its research efforts through three cooperative institutes: the Joint Institute for Study of the Atmosphere and Ocean (JISAO), with the University of Washington, the Joint Institute for Marine and Atmospheric Research (JIMAR), with the University of Hawaii and the Cooperative Institute for Marine Resource Studies (CIMRS) with Oregon State University. These institutes were established between NOAA and the Universities to provide a bridge between the academic community and PMEL scientists working in climate dynamics, environmental chemistry, tsunami propagation, fisheries oceanography, and seafloor spreading processes.

CLIMATE RESEARCH

The NOAA Ocean Climate Program was developed following the passage of the National Climate Program Act in 1978 in response to increased public awareness on the effects of short- and long-term climatic changes, particularly the effects on food and energy, and a concern about the effects of technology and population growth on world climate.

Understanding and forecasting climatic change requires an understanding of the processes of heat, moisture, and momentum exchange between the ocean and atmosphere as well as the large-scale transports of heat within the atmosphere and ocean. PMEL's ocean climate research program investigates the problem in studies of both local (small-scale) and basin-wide (large-scale) ocean dynamics and the coupled ocean-atmosphere circulation. A major research goal is to determine the relative importance of the physical mechanisms that generate anomalies in sea-surface temperature distributions in the tropical ocean. A crucial step in reaching that goal is to develop and validate ocean circulation models that are capable of simulating the evolution of such globally important events as El Niño.

Heat transport by major western boundary currents (the Gulf Stream and the Kuroshio in the Northern Hemisphere) is also postulated to have an important effect on world climate. Western boundary current studies at PMEL continue to focus on the Florida Current as part of the Subtropical Atlantic Climate Studies (STACS).

PMEL also conducts two important marine chemistry research programs for NOAA under the National Climate Program. These studies relate to the ocean's behavior as a sink for atmospheric carbon dioxide (CO_2), which has been steadily increasing over the past century. One program measures the flux of anthropogenic fluorocarbons into the ocean in order to trace gas diffusion across the ocean-atmosphere boundary and within the ocean. The other examines the role of biologically produced, particulate calcium carbonate as a sink of CO_2 at high latitudes. Together the programs will help determine the potential of the oceans for absorbing CO_2 and modifying global warming.

Accomplishments FY 1988

EQUATORIAL DYNAMICS

In support of the Tropical Oceans and Global Atmosphere (TOGA) program, PMEL maintains an array of moored sensors in the vicinity of the Equator in the tropical Pacific. The sensors measure the vertical distribution of the current velocity and temperature between the surface and 250 m. Off-equatorial measurements of the temperature profile down to 500 m are made from ATLAS moored thermistor chains. Both types of moorings transmit wind velocity, air tempera-

ture and sea-surface temperature in real time. Wind stations are maintained in the western and central Pacific (Kapingamarangi, Nauru, Baker and Christmas Is.).

The data are used collectively, along with other data sets, to diagnose the current state of the tropical Pacific, to validate the operational ocean general circulation model at the National Meteorological Center, in research on air-sea interaction processes responsible for annual and interannual variability of the tropical Pacific, and for a variety of Laboratory investigations.

Current Variations During the 1986-87 El Niño-Southern Oscillation Event

Data from the equatorial current meter moorings were used to describe the evolution of the 1986-87 El Niño-Southern Oscillation (ENSO) warm event that terminated in December 1987. In terms of current variations it is the best documented warming event in the Equatorial Pacific.

Our analysis of the mooring data indicated that remotely forced intraseasonal Kelvin waves with periods of roughly 2-3 months were an important source of temperature and current variability in the eastern Pacific during 1986-87. These waves appear as 30-40 m oscillations in thermocline depth and 20-40 cm s^{-1} fluctuations in zonal current. These fluctuations are presumably forced in the western Pacific in the wind fields that have similar time scales. Superimposed on these remotely forced oscillations are local wind forced variations.

In contrast, the most striking feature of the currents at 110°W during the 1982-83 ENSO was the disappearance of the Undercurrent in January-February 1983. The undercurrent has long been assumed to be a permanent feature of the western Pacific equatorial circulation in the region east of 137°E; this observation is the first documentation of an ENSO-related disappearance in the western Pacific.

We completed a comparison of buoy-measured surface winds and several operational wind products, and investigated the effect of SST fluctuations on local wind. We found a major discrepancy between in-situ observations and tropical wind products. In general, operational model winds tended to agree with each other better than with the observations. In the eastern Pacific there was a systematic bias of the models toward a relatively weak southerly component. A possible contribution to this error is the improper treatment of the atmospheric boundary layer in the models and a failure to adequately account for the influence of SST gradients on boundary layer winds. The influence was examined with the moored-buoy data by comparing SST changes with surface wind changes in the vicinity of the Equatorial SST Front in the eastern Pacific. Clear evidence of modulation of surface winds by wavelike perturbations in this front was found, and changes in meridional wind and meridional SST gradient were correlated. The results of these studies suggest that assimilation of the surface wind into the atmospheric models may lead to substantially improved tropical surface wind fields.

Hindcasts of the 1982-83 El Niño

We completed a series of ocean circulation model hindcast studies of the 1982-83 El Niño (1) to examine the sensitivity of the computed dynamic height field to changes in the wind field, (2) to

evaluate the success of the SST simulations and diagnose the mechanisms of SST change during this period, and (3) to determine the area over which the winds must be known in order to reproduce the equatorial behavior of the standard unmodified computation. We found that specification of the winds within 7° of the Equator resulted in a very good reproduction of equatorial conditions but that unacceptable differences resulted when only the winds within 3° of the Equator were specified. We also found that specifying the winds only in the western Pacific resulted in poor simulations. These results indicate that the equatorial ocean is forced by winds mainly near the Equator. They also suggest that there is no need to invoke the propagation of ocean anomalies poleward of 7° to explain the major aspects of the 1982-83 El Niño event.

Role of Rossby waves in El Niño events

Baroclinic Rossby waves, which propagate relatively slowly westward in off-equatorial regions, have been proposed as a possible mechanism for controlling the quasi-periodic timing of El Niño events. For a long time Rossby waves have been thought to be important in the adjustment of the tropical ocean to variable forcing by the winds but they rarely have been observed clearly. Evidence that these waves reflect off the American continent after the equatorial anomalies have propagated poleward along the eastern boundary was sought in an analysis of observations collected in ship-of-opportunity programs. The depth of the 20°C isotherm, which is a proxy for thermocline depth, was determined from these data and examined for evidence of the westward propagation that would be associated with the presence of Rossby waves. We found that the 1972 El Niño was reasonably well observed and a Rossby wave reflection from the North American continent (5-10 m depression) could be traced across the entire Pacific basin and was identifiable more than 5 years after the event. By modeling the expected response to a pulse-like disturbance using ray theory, we showed the observed thermocline signal to be a baroclinic Rossby wave. We also concluded that the thermocline depression that spreads poleward along the North American coast in the aftermath of El Niño leaks energy in the form of long baroclinic Rossby waves, which can be observed across the entire width of the Pacific. These waves lose about half their amplitude through dispersion before reaching the western boundary, so it remains an open question whether they provide a sufficiently strong trigger for a subsequent El Niño.

WESTERN BOUNDARY CURRENTS

Observations of the Florida Current transport derived from the cross-stream voltages on an abandoned cable between Jupiter, Florida, and Settlement Point, Grand Bahama Island (GBI), and an active telephone cable between West Palm Beach, Florida, and Eight Mile Rock, GBI, are continuing.

A magnetometer was installed at Settlement Point, which will increase the accuracy in estimating the geomagnetic noise that is removed from the cable data, thus improving the accuracy of the tidal estimates and shortening the time for reducing the cable data to transport values from 2 months to a few days. We improved our method for determining the transfer functions that are needed for removing the geomagnetic induced noise.

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We constructed theoretical 2-D electromagnetic models for studies concerning the calibration factor needed to construct transport values from the cross-stream voltages. The calibration factor was found to be insensitive to the cross-stream spatial variability if the cable length is at least 10 km long. These results have negative implications on using short span electric field recorders for transport measurements.

MARINE AND ATMOSPHERIC CHEMISTRY FOR CLIMATE CHANGE

One of the significant environmental issues of the next century will be the potential for systematic changes in the Earth's climate due to increases in the atmospheric burden of CO_2 and other greenhouse gases including methane, chlorofluorocarbons (CFCs), and carbon monoxide.

Tracer Program

We measure chlorofluorocarbons (CFCs) in the sea as time-dependent tracers of water mass formation and thermocline ventilation of other gases. Information about these processes is used for assessing the moderating role of the oceans in delaying and damping the global warming predicted for coming decades.

Two field programs were accomplished in 1988 to collect data on tracer distribution. A spring expedition aboard the NOAA Ship *Oceanographer*, from Dutch Harbor, Alaska, to American Samoa, permitted a detailed meridional survey of climate-forcing trace gases and aerosols as a function of latitude in the central north and equatorial Pacific Ocean. This cruise repeated the route of the 1983 chemical/hydrographic survey, permitting the evolution of the transient tracers (CFC-11, CFC-12, fossil fuel CO_2) in the thermocline during this 5-year interval to be determined. The water column measurements also included precise determinations of temperature, salinity, oxygen, and nutrients. The saturation state of the surface waters for the carbon cycle trace gases CO_2, CO, and CH_4 was accurately determined by continuous, automated gas chromatography. The trace gas signature of the surface waters at the equator (25% CO_2 supersaturation) represented the normal upwelling state following the conclusion of the 86/87 ENSO event.

The second field program was a cooperative Western Equatorial Pacific Ocean Climate Study (WEPOCS) (June-July, 1988) with AOML (Miami). PMEL was responsible for the CFC measurements (2000 samples) to determine the source waters of the equatorial current system (Equatorial Undercurrent [EUC], North Equatorial Countercurrent [NECC]), and the flow-through to the Indian Ocean.

A workshop in June brought together ocean CO_2 researchers to reassess the source/sink character of the North and Equatorial Pacific Ocean from both a modeling and a measurement perspective. The workshop produced a working agreement and format for reporting and synthesizing existing and future measurements of pCO_2. The goal is to improve climatology for the seasonal and regional air-sea exchange of CO_2 of the entire Pacific basin.

The PMEL tracer program contributed to a GFDL general ocean circulation model simulation of fluorocarbon transients by supplying pan-Pacific chlorofluoromethane (CFM) distribution measurements for model evaluation. The first model results, although showing general agreement with the measured distributions, revealed a much less efficient invasion of tracer than that determined by the observations. A second, global ocean CFM tracer simulation with more realistic forcing and isopycnal formulation is under way and will probably produce model tracer fields in much better agreement with the PMEL CFC measurements.

Marine Sulfur

Biogenic emissions of dimethylsulfide (DMS) from the ocean are a major source of the background sulfate aerosol particles in the marine troposphere. These particles act as cloud condensation nuclei and are calculated to have a strong effect on the opacity of marine clouds. In this role, DMS emissions may be important to the radiative budget of the Earth.

DMS emissions and aerosol particle formation were studied during FY 1988 in the central Pacific Ocean aboard the NOAA Ship *Oceanographer* along 170°W from Dutch Harbor, Alaska, to American Samoa. In the temperate latitudes, the sulfur cycle was dominated by anthropogenic sulfate presumably from the Asian continent. DMS emissions were higher between 10°N and 10°S, and could account for the atmospheric burden of sulfur dioxide and sulfate.

Plans FY 1989

EQUATORIAL DYNAMICS

- Complete analysis of hydrographic, chemical, and velocity data collected on the TEW section along 15°S aboard the *Researcher* (*Malcolm Baldrige*) and *Oceanographer*.

- Perform diagnostic analysis of general ocean circulation model hindcast of the 1986-87 El Niño with improved surface heat flux parameterization.

- Provide a description of the data collected from current meter and ATLAS moorings, hydrographic casts, and acoustic Doppler current profiling during the 1986-87 El Niño.

- Expand salinity and real-time current measurement program to the western Pacific.

- Begin analysis of data collected in the EPOCS North Equatorial Countercurrent array centered at 7°N, 140°W.

- Complete study comparing sea-level and XBT dynamic height indices of the variations of central Pacific geostrophic surface currents.

WESTERN BOUNDARY CURRENTS

- Compute transfer functions based on data from the magnetic site installed at Settlement Point.

- Compare the atmospheric sea-level pressures over the Northern Hemisphere with the Florida Current transport variations for climate studies.

MARINE AND ATMOSPHERIC CHEMISTRY FOR CLIMATE CHANGE

- Establish a facility at PMEL for measuring and interpreting transient tracers (CFCs) in the North and South Pacific. This facility will more than double the existing annual capacity for CFC sample analysis, allowing for the extension of the tracer coverage to ships of opportunity operating in the remote and poorly sampled Southern Ocean.

- Continue the program of repeated meridional sections of the Pacific Ocean in order to capture the time-dependent, basin-wide distributions of anthropogenic chemical tracers (CO_2, CFCs, etc.) entering the thermocline.

- Conduct a major oceanographic/atmospheric expedition to the remote southeast Pacific Ocean to survey the latitude distribution of climate-forcing trace species in the marine boundary layer and upper ocean. Of particular importance will be the penetration of transient tracers (CFM, tritium, fossil fuel CO_2) into the Antarctic Intermediate Water of the Southern Ocean.

- Initiate a program of modeling the measured transient tracer fields in the North Pacific thermocline (1981-1987), using the GFDL ocean general circulation model.

- Continue the collaborative program with GFDL to compare and interpret the measured CFM tracer fields against those generated by successive generations of the ocean general circulation CFM tracer simulation.

- Complete the analysis and publication of the existing PMEL CFC surveys in the eastern (1981-86), central (1983-88) and western (1982-87) North Pacific Ocean. This program has permitted the basin-wide tracer transient fields to be mapped with 5-year resolution.

- Field a state-of-the-art analytical system for automated, precise determination of total CO_2 in seawater by the coulometric method on the Southern Ocean expedition.

- Refine, document, and improve the prototype system ("data logger") for automated and continuous measurement of critical atmospheric and oceanographic parameters required to interpret the air-sea exchange and marine photochemistry of climate-forcing trace species.

- Design and carry out cooperative field programs to quantify the relationship between the flux of marine sulfur (DMS) to the atmosphere, and the local atmospheric abundance of the sulfate aerosol particles thought to control cloudiness.

- Improve analytical methods for determining ammonia at natural levels in seawater and rain-water, and in the atmosphere (jointly with Aeronomy Laboratory).

MARINE RESOURCES

Accomplishments FY 1988

VENTS PROGRAM

Hydrothermal venting processes, which are now known to occur along the entire global seafloor spreading center system, are a significant source of heat and mass being introduced into the global ocean. To assess the chemical oceanographic effects of these processes and thereby make it possible to predict the chemical consequences of hydrothermal venting, the VENTS Program is engaged in a multidisciplinary effort to (1) determine the effects of hydrothermal venting on seawater chemistry, and the fate of hydrothermal mass and heat, through chemical and geochemical studies, (2) determine the physical oceanographic processes whereby hydrothermal fluids and gases are distributed throughout the ocean, and (3) determine the conditions that control the location and duration of active vent sites, through geological and geophysical studies.

The laboratory and field programs involve collaboration with scientists from the United States Geological Survey, the Geological Survey of Canada, the Universities of Washington, Oregon State, Florida, Michigan, California, and Hawaii, the University of Victoria (Canada), and Woods Hole Oceanographic Institution.

Southern Juan de Fuca Ridge

Investigations of the Juan de Fuca Ridge were concentrated on two principal areas, the southern and central segments. The southern segment actually comprises two slightly offset segments of approximately equal length (Rift A and Rift B). Within the region where the ends of the two subsidiary segments are offset but adjacent, two anomalously large hydrothermal vents have been observed. These vents have been termed "megaplumes" because they contained massive quantities of hydrothermal heat and chemicals, comparable with amounts that would be generated by hundreds to thousands of "normal" high-temperature hydrothermal vents.

The tectonic or volcanological process (or processes) that generated these anomalous vents appears to be episodic, and the physical and chemical characteristics of the vents indicate that their initial temperatures were several hundreds of degrees centigrade. Another distinctive characteristic of the megaplumes is that, because of their relatively great buoyancy, they are found considerably higher in the water column than the plumes associated with steady-state hydrothermal low- and high-temperature vents.

Initial interpretations of the field results indicate that (1) the source of the vigorous "normal" plume found in the vicinity of the Southern Juan de Fuca Ridge offset may be the very extensive

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low-temperature vent fields that were discovered to extend for nearly 2000 meters along the strike of the tip of the southern, Rift A, segment, and (2) the megaplumes may have originated in association with extrusion of very young volcanics found along the Rift A ridge axis or, (3) they may have been caused by fault-induced breaching of large subsurface volumes of trapped hydrothermal fluids.

During 1988, an intensive program was carried out aboard the *Atlantis II* and NOAA Ship *Discoverer* to map the distributions of hydrothermally derived Si, ^{3}He, Mn, Fe, Rn, CO_2 and heat from the vent orifices to distances up to 150 km away from the spreading centers. The results show that hydrothermal emissions from the southern Juan de Fuca ridge form a 500-m-thick plume elongated in the direction of net current flow and centered on the 27.69 potential density surface. The ratios of ^{3}He and Si in the buoyant plume are in good agreement with the low and high temperature vent fluids.

These ratios seem to indicate that the anomalous plumes are related to hydrothermal sources along the northeast spreading-center system and that the volume of output may vary dramatically. Profiles of dissolved Si along the 45°N and 47°N parallels show middle-depth (2100 m) anomalies that extend across the eastern half of the North Pacific and are segregated into centers of high and low concentrations. A major question in light of the Megaplume I and II discoveries is whether the high- versus low-Si anomalies are related to episodic hydrothermal venting out of the Gorda-Juan de Fuca-Explorer system.

Another important result of this study is that negative anomalies of dissolved phosphate were observed directly over the ridge axis with corresponding positive anomalies of phosphorus in the particulate phase. Comprehensive analysis of the particulate phases with our scanning electron microscope indicate that the phosphorus was being scavenged from solution by newly formed iron oxyhydroxides of hydrothermal origin which end up as a phosphorus-rich component of the underlying sediments. Mass balance calculations suggest that a minimum of approximately 18% of the total annual phosphorus sink in the oceans is due to scavenging by hydrothermal emissions. Similarly, geochemical evidence for scavenging of the cations Ba, Ni, Cu, Zn, and Pb, and oxyanions P, V, Cr, and As by hydrothermal oxyhydroxides was also observed in the water column and underlying sediments. These results demonstrate the important role of hydrothermal emissions as scavengers of chemicals from seawater. The resulting depletions can also serve as a tracer of dispersing plumes.

Compositional stability of the southern Rift A regional plume chemistry has been observed through a 5-year time series of annual month-long plume surveys. From this unique time series for plume chemistry, PMEL investigators have inferred that venting of hydrothermal fluids of constant chemical composition has occurred at the southern Rift A vent sites for at least 5 years. This is consistent with direct observations of vent fluid chemistry made at other ridgecrest spreading centers where decadal-scale compositional uniformity has been observed.

Observations made of the Rift A segment of the Juan de Fuca Ridge during the past 3 years have provided the first full-segment perspective for plume chemistry. Unlike the compositionally uniform plumes observed at the southernmost Rift A vents, the plumes overlying the north-

central and north regions of the rift are chemically diverse. Such intra-segment chemical diversity must be accounted for in the assessment of hydrothermal input to the regional ocean.

Central Juan de Fuca Ridge

The central segment of the Juan de Fuca Ridge is dominated by Axial Volcano, a large submarine hotspot volcano situated astride the axis of seafloor spreading. For the past several years, an active hydrothermal vent field within the volcano's summit caldera has been the focus of a number of VENTS Program studies. One of Axial's vent fields is uniquely situated for investigations of hydrothermal processes because it is relatively small but contains a wide variety of hydrothermal environments including low- to high-temperature vents, massive sulfides, and extensive and thriving hydrothermal animal communities. Vent fluids within the Axial caldera also exhibit important chemical diversity including fluids that have apparently boiled and separated into brine and vapor phases.

From FY 1987 *Alvin* sampling and photographic data we produced maps of the Axial vent field, the most detailed and comprehensive maps of an active deep-sea hydrothermal vent field in existence. The maps provide a framework for understanding the origin of the vent field as well as a base for numerous other geophysical, chemical, oceanographic, and biological time series experiments.

We made significant progress toward the goal of being able to use acoustical backscatter to recognize and predict various geological environments at reconnaissance scale surveys. New mathematical approaches, including fractal geometry and spectral analysis, were developed and tested, which allow the backscattered acoustic signal from sidescan sonar surveys to be statistically categorized in terms of rock type and bottom roughness. These results are now being compared with the "ground truth" maps mentioned above.

Samples obtained with the research submersibles *Pisces* and *Alvin* at the ASHES vent field at Axial Volcano during 1986, 1987, and 1988 have confirmed the presence of vapor-rich, and probably phase-separated and segregated, vent fluids. This is the first documentation of such highly phase-fractionated fluids. Ongoing study of these fluids presents a unique opportunity for VENTS investigators to understand the processes and effects of phase separation during venting. Local deposition from vented fluids, plume formation and plume chemical evolution are predicted to be significantly influenced by phase-separated fluids.

Gorda Ridge

The northern 50-km-long segment of the Gorda Ridge has a well-defined rift valley and a diversity of igneous rock types, unlike the Juan de Fuca Ridge or any of the other intermediate- to fast-spreading ridges in the Pacific Ocean. Significant advances were made in locating and characterizing two hydrothermal venting zones in this northern segment, previously known only from regional water columns surveys.

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Interpretation of a high-resolution sidescan sonar (SeaMarc IA) survey of the northern segment performed in August 1987 revealed that the locations of the two venting zones (GR-14 and GR-15) are controlled by the intersection of a regional fracture trend parallel to the ridge axis, and that an anomalous transverse trend is related to the local stress regime. This finding both elucidates the seafloor controls of the hydrothermal activity and targets the two venting zones for near-field characterization.

A dive series with the U.S. Navy DSV *Sea Cliff* was organized and conducted (September 1988) to close range on, and initiate characterization of the high-temperature venting zone at the GR-14 site. This involved a cooperative scientific team from NOAA, USGS and academia sponsored by the Gorda Ridge Technical Task Force of USGS's Minerals Management Service.

Technical Achievements

Following the successful use of the S3 (Submersible-Coupled VENT Fluid Sampling and Sensing System) during the 1987 field season, the system was further refined. The S3 has dramatically increased precision in chemical analyses of the vent fluids, which are a basis for assessing the chemical oceanographic impact of hydrothermal activity.

During FY 1988, an in-situ chemical analysis system was deployed to function in two modes--as a stationary monitor of the temporal chemical variability of active venting systems, and as a chemical scanner to map the chemistry of seawater/vent fluid mixtures as they are found in various environments close to, and at a distance from, the vents. The system measures variations in temperature, iron, manganese, sulfide, and pH. These are chemical and physical characteristics of a typical hydrothermal plume and have key roles in chemical reactions of the vent fluids with their near-, middle-, and far-field environments.

FISHERIES OCEANOGRAPHY COORDINATED INVESTIGATIONS

PMEL's Fisheries Oceanography Coordinated Investigations (FOCI) is a joint effort with the Northwest and Alaska Fisheries Center to study recruitment variability of commercially valuable fish and shellfish in the Gulf of Alaska and Bering Sea. The research is aimed at determining (1) what meteorological, oceanographic, and biological conditions are correlated with historical year-class success, (2) whether there are interannual variations in transport that affect larval concentrations, and (3) how small-scale physics, food availability, and predation affect mortality.

We found a relation between estimates of abundance of age-3 pollock recruits and the Northeast Pacific Pressure Index (NEPPI), a measure of the strength and location of the Aleutian Low. The relation suggests that as the index increases, the number of recruits decreases. This implies good recruitment from fish spawned during springs when the Aleutian Low is weak, absent, or displaced.

Comparing 1981 and 1985, we found evidence that physical processes were responsible for a consistent decline in pollock spawner biomass and mean egg concentration. Data from CTD and

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moored current meters show that there are two modes of larval transport in the region: (1) the rapidly moving Alaska Coastal Current (ACC) which flows seaward, and (2) the weaker mean flow toward the southwest shoreward of the ACC. Apparently, cross-channel disturbances (eddies or meanders) in the flow field incorporated most of the emerging 1985 larval year-class into the ACC, transporting them away from nursery grounds.

Analysis of long-term (1978 and 1984-87) current, wind, and freshwater discharge data elucidated seasonal transitions in the ACC and on the adjacent shelf that could affect larval concentrations. The spring transition has exhibited two distinct patterns: (1) a steady smooth decline in currents between December and June, or (2) a more rapid approach to near-zero currents in February and March, followed by stronger than usual currents in April through May. The latter was observed in 1985. The strength of the ACC can be such that planktonic material, including larval pollock, would be removed from the Strait within 2 to 3 weeks, that is, in less time than it takes the larvae to develop.

Using extensive CTD data, acquired since 1976, we found extreme variability of baroclinic transport over periods of less than 3 days. Variation may be related to complex flow features observed in dynamic topography and satellite images. Based on the data since 1976, bottom water properties varied considerably; in particular, relatively cold freshwater was present during much of 1986. Abnormally cold conditions may affect egg development and adult pollock growth and maturation.

Current, temperature, and salinity data from a long-term mooring located on the continental slope adjacent to the sea valley show a large offshore excursion of the Alaskan Stream during spring. This resulted in relatively weak flow toward the northeast (i.e., reversed flow) and a change in water properties in the vicinity of the mooring. More pollock have been observed spawning here than over other portions of the slope (although in much smaller numbers than in Shelikof Strait) and concentrations of eggs and larvae are also relatively high. It is possible that this spring excursion affects both initiation of spawning and retention of eggs and larvae.

Plans FY 1989

VENTS PROGRAM

• Continue the analysis of the heat-^{3}He-Si relationships in off-axis regions to determine the effects of steady-state and episodic venting on the regional distributions of these constituents in the North Pacific.

• Continue the analysis of dissolved- to particulate-phase relationships for trace elements in the water column.

• Analyze sediment trap materials for major and trace elements and determine chemical fluxes to the sediments in on- and off-axis regions west of the Juan de Fuca Ridge.

- Collect and analyze vent fluids and overlying plume waters to investigate the relations between venting sources and the dispersing neutrally buoyant plumes. Determine the relative contributions of low- and high-temperature venting to plumes, using data from these samples and determinations.

- Refine our understanding of the rates and processes that control the physical and chemical evolution of vent fluids as they mix with ambient seawater and are dispersed away from the vent field.

- Analyze southern Juan de Fuca photogeological information for the purpose of constraining the location and effects of megaplume hydrothermal bursts.

- Continue to merge sidescan sonar, water column, and photogeological information into an integrated digital data base for compilation into detailed hydrothermal-parameter maps.

- Conduct geological and geophysical, chemical, and physical oceanographic surveys from the *Discoverer* at the megaplume sites and at Axial Volcano for the purpose of continuing time series experiments focused on causes and effects of all scales of hydrothermal venting on regional ocean chemistry.

- Continue to monitor and analyze bottom pressure recorder data for evidence of tectonic deformation of the Axial summit caldera.

- Analyze the results of surveys to determine the distribution and characteristics of hydrothermal venting along the northern segment of the Juan de Fuca Ridge.

- Continue to refine the quantitative ability of reconnaissance sidescan sonar survey data to discriminate specific seafloor geological (including hydrothermal) environments.

- Continue modeling work on the fate of hydrothermal effluents, particularly Mn, in middle and far fields.

- Continue work on locating and characterizing high-temperature hydrothermal venting sites at the northern Gorda Ridge, by analyzing and interpreting data sets from September 1988 DSV *Sea Cliff* dive series SeaMarc IA high-resolution sidescan sonar records.

FISHERIES OCEANOGRAPHY COORDINATED INVESTIGATIONS

- Extend estimates of age-3 pollock recruitment series back to 1951, and investigate climate-recruitment relationships for modeling.

- Compare fluctuations in the Gulf of Alaska fishery with those in the Bering Sea, eastern Gulf of Alaska, northeastern U.S. coast, and Norway.

- Develop a mechanistic model of a larval patch including biotic and abiotic environment.

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- Develop a pollock mortality schedule for the first 6 months of life to determine which survival hurdles are most significant.

- Continue long-term monitoring of water properties, Eulerian and Lagrangian currents, and island-based wind; continue satellite image analysis and pollock egg and larval surveys.

- Examine resorption of eggs as a possible factor in determining final egg production.

- Examine relationships between spawning and fecundity versus stock size and physical conditions, using observations from 1982 and 1986-88.

- Compare local with synthetic winds to improve estimates of the regional wind field and to examine forcing for current variability.

- Synthesize Eulerian, Lagrangian, dynamic topographic, and inferred satellite image information on dominant scales of current variability and compare with those of zooplankton and pollock larvae.

- Conduct a field experiment to examine food supply, predation, and dispersion as causes of mortality.

- Develop techniques for acquisition, processing, and analysis of LORAN-C-tracked buoys.

- Conduct field and laboratory studies on vertical migration of pollock larvae.

MARINE OBSERVATION AND PREDICTION

Research is directed toward understanding and improving the prediction of phenomena of concern to marine warning and forecasting services. Research subjects include sea-ice processes, arctic oceanography, vessel icing, and tsunami propagation. PMEL scientists work closely with colleagues at operational service components of NOAA such as the National Weather Service and the Navy-NOAA Joint Ice Center. The Arctic research is also applicable to NOAA's climate studies. Research is carried out through a combination of field measurements, remote-sensing techniques, and numerical modeling.

Accomplishments FY 1988

ARCTIC RESEARCH

The Beaufort Sea Mesoscale Circulation Study

The Beaufort Sea Mesoscale Circulation Study was initiated in the autumn of 1986 and has included measurements of currents, winds, and ice velocities, as well as observations of state variables and nutrient distributions in the ocean and state variables in the polar atmosphere, principally between Barrow and Demarcation Point along the Alaskan Beaufort Sea shelf. Data collection continued through April 1988 when the remaining current meter moorings were recovered through the ice and the coastal anemometers were dismantled. The total data set is extraordinary in the temporal and spatial extent of its coverage, and in the variety of its constituent measurements. The data set is also extremely large, and its full reduction and analysis will improve our understanding of the shelf circulation and its forcing, and the conditions important to the marine ecology of the area.

The FREEZE Experiment

Throughout the polar regions there are oceanic areas that remain nearly ice free when temperature conditions would favor an ice cover. These ice-free areas are called polynyas and typically occur along arctic coasts where off-shore winds or currents continually remove the ice as it forms. Because ice extrudes salt as it forms, continual freezing in a polynya can cause a considerable brine enhancement, which may affect the water density structure and current field beyond the polynya, through mixing and advection of the brine.

The objectives of PMEL's FREEZE Experiment were to examine the fine-scale process of freezing in the autumn in the context of the regional environmental conditions just prior to and during initial freeze-up. In October 1987, we deployed current meter and pressure gauge moorings, set out drifting ice buoys to trace the advancing ice edge, and mapped heat and salt budgets

using data from CTD casts. Additionally, several investigators participated in a 10-day study involving a series of daily cruises during late November 1987 aboard the tugboat *Nanuk III* from Nome, Alaska. The experiment used a CTD attached to a remotely operated vehicle to make horizontal CTD "casts" in order to observe spatial variability of the brine rejection. Meteorological information was also collected by measuring solar radiation, regional sea-level pressure, and winds.

The initial data analysis suggests that in light to moderate winds there is little structure to the ice crystal formation and brine rejection. However, in higher wind situations the freezing is organized into rows, and these rows are probably formed by secondary circulations driven by Langmuir mechanics. This understanding is an important first step toward defining external parameters for predictive modeling of ice formation.

Investigations in the Greenland Sea

The long-term goal of these investigations is to understand the Greenland Sea's role in global climate and in the large-scale dynamics of the atmosphere and the ocean. To do so it is important to quantitatively understand major water mass transformations and ventilating mechanisms, regional circulation and mixing, variability of the sea ice and its relation to the ocean circulation, and exchanges with the atmosphere.

During FY 1988 efforts were concentrated on the first two issues by conducting hydrographic and circulation investigations during four cruises. The work is part of the Greenland Sea Project and cooperative with institutions in Europe and North America.

Analysis of the first hydrographic data set has shed new light on the recently discovered outflow into the Greenland Sea of saline Arctic Ocean deep water and on the formation of Norwegian Sea deep water.

* High-salinity water in the Greenland Sea originates at middle depths (1600-1700 m) in the Arctic Ocean.

* This water flows southward along the Greenland slope until the bathymetry forces a divergence in the southwestern Greenland Basin. The most saline water continues southward into the Iceland Sea, rather than flowing into the Norwegian Sea through gaps in the Mohn Rise.

* Within the Greenland Sea, the saline Arctic Ocean water is mixed with Greenland Sea deep water in an approximately 3:7 ratio to produce Norwegian Sea deep water.

* The production rate of new deep water with Norwegian Sea properties is about 2 Sv $(2 \times 10^6 \text{ m}^3 \text{ s}^{-1})$, corresponding to a replacement time of about a decade. This is less than one-half the rate calculated from recent tracer box models, thus suggesting that not all the new deep water moves into the Norwegian Sea, but rather that a significant portion remains in the Greenland Sea.

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Sea-Ice Processes and Modeling

A sea-ice, barotropic-ocean model was developed to investigate the coupling of ice motion to wind-driven coastal currents. The model emphasizes the ice thickness-strength relation on downwind coasts, and resolves the oceanic boundary layers for finite depth situations through the use of vertical structure functions. The model shows clearly that the ice-thickness/motion feedback is important on scales smaller than 10 km and that the relation of ice velocity to wind stress in coastal seas is variable because the ocean slope current responds only to the alongshore component of the wind. This is a major step in providing quality forecasts of coastal ice motion.

Arctic Fluxes

We analyzed several data sets collected from aircraft flying over the St. Lawrence polynya in the Bering and Beaufort Seas in 1982 and 1983. The data were collected in an effort to measure the turbulent transport of heat and momentum across the polynya. An area of predominantly white young ice produced a measured drag coefficient (C_D) of 1.5×10^{-3}, which was in agreement with previous measurements. An area including three different ice regimes (frazil ice, grey young ice, and white young ice) produced a measured C_D of 3.2×10^{-3}. This high value was traced to more efficient turbulent mixing due to flow over and around the mountains on St. Lawrence Island. The air directly in the lee of the mountain was 6°C warmer than surrounding air and the wind field showed the presence of a strong narrow area of convergent flow where the sensible heat flux was 1000 W m^{-2}.

TSUNAMIS

Four deep ocean bottom pressure recorders (BPR's) were successfully recovered (and redeployed) in the Gulf of Alaska and in the Axial Caldera off the U.S. west coast. Analyses of the records revealed success in detecting three seismic surface waves and two tsunamis generated a few hundred kilometers south of Cape Yakataga, Alaska, on 17 and 30 November 1987 and 6 March 1988. These measurements constitute the first multiple-gauge measurement of tsunamis in the open ocean.

An agreement was reached with the National Ocean Service for its Ocean Mapping Section to perform a multibeam bathymetric survey of the Shumagin Seismic Gap, a region along the Aleutian Trench associated with high seismic potential. Thus, should the predicted tsunamigenic earthquake occur, this survey would provide pre-event baseline data for comparison with a post-event survey; together, the data would provide critical information on the vertical and horizontal extent of ocean bottom deformation corresponding to the tsunami source region.

Plans FY 1989

ARCTIC RESEARCH

• Analyze 2 years of current meter, hydrographic, and meteorological data for the Beaufort Sea Mesoscale Circulation Study.

• Recover and redeploy current meter moorings and make additional heat and salt content surveys for the FREEZE Experiment from the NOAA Ship *Surveyor* during September-October 1988 and analyze data from the 1987-88 field year.

• Extend the one-dimensional sea-ice barotropic-ocean model for coastal oceans to two dimensions, using the combined Bering-Chukchi shelves as an example.

• Conduct volumetric surveys in the Greenland Sea during November-December 1988 on the R/V *Meteor*, during March-April 1989 on the R/V *Valdivia*, and during June-July 1989 on the R/V *Polarstern*. This work is part of the Greenland Sea Project.

• Recover and redeploy instrumented moorings in the Greenland Sea and in Denmark Strait during June-July 1989 on the R/V *Polarstern* and on the R/V *Cirolana*. The work on the *Polarstern* is part of the Greenland Sea Project.

• Initiate a study of air, ice, and ocean north of the Greenland Sea, using icebreaker-based observations from September 1988-February 1989 and NOAA P-3 aircraft observations from March-April 1989. The work is part of the Combined Eastern Arctic Experiment (CEAREX).

TSUNAMIS

• Prepare report on the three Alaskan tsunamis.

• Perform analyses of coincident BPR and GEOSAT altimeter observations.

• Recover and re-deploy all deep-ocean BPRs.

MARINE ENVIRONMENTAL ASSESSMENT

Marine environmental assessment at PMEL emphasizes understanding the complex physical and geochemical processes that ultimately determine the health of marine systems and their ability to assimilate contaminants. Included are studies of the geochemistry of trace metals and organic compounds, distributions of hydrocarbons and synthetic organics, coastal and estuarine circulation, and transport processes. Although the geographic focus of these studies has been Pacific Northwest and Alaskan coastal and estuarine waters, the scientific knowledge acquired and methodologies developed are applicable to other marine systems.

Accomplishments FY 1988

LONG-RANGE-EFFECTS RESEARCH

In response to the Marine Protection, Research and Sanctuaries Act of 1982 and the National Ocean Pollution Research and Development and Monitoring Planning Act of 1978, PMEL has addressed environmental concerns associated with marine disposal and transport of municipal and industrial wastewater and the reaction of marine systems to continuing influx of contaminants. PMEL is examining the role of suspended particulates in transporting contaminants and in removing them from marine systems. Researchers have been investigating the mechanisms by which heavy metals and organic pollutants partition between water and particulates and are subsequently buried in sediments or advected from the estuary. As these processes become better understood, the long-term effect of chronic, low-level input of pollutants on marine resources will be assessable. Therefore, studies in the Puget Sound-Strait of Juan de Fuca estuarine system, under way for many years, are leading to a better understanding of the ability of estuaries to accommodate pollutant inputs.

In 1988, continuing emphasis was placed on simulation modeling of the present data base and on geochemical process studies; descriptive physical and chemical field studies were severely reduced while an assessment was conducted of data and knowledge gaps.

Estuarine Circulation

The replacement of bottom water in Puget Sound has been studied for many years, because it is a dominant process responsible for flushing some contaminants. Previous studies showed that bottom-water inflow increases during spring and fall equinoctial periods, when neap tides occur and mixing is minimal over the entrance sill. Our studies have now shown that the increased inflow starts before minimum neap tides. Our calculations with these data in a simple model demonstrate that this is an effect of variations in the horizontal density gradient at the mouth of the estuary, caused by salinity variations outside the mouth. This time-dependent process may be

responsible for changing inflow characteristics on time scales between wind effects and seasonal effects, and it may be important in other estuaries.

Estuarine Transport

During 1988, the study of the estuarine transport of trace metals moved from the field into the laboratory. We performed experiments using ambient Puget Sound seawater to study the rate of conversion of dissolved manganese (Mn) to particulate Mn. The kinetic data obtained will be incorporated into the laterally averaged model of Puget Sound to provide an understanding of the role of Mn oxide surfaces relative to toxic trace metals, which in turn will lay the foundation for models attempting to describe the transport and fate of particulate-reactive toxic trace metals such as lead (Pb).

The fate of copper (Cu), unlike metals like Pb, seems to be controlled by the behavior of dissolved and particulate organic matter. We conducted laboratory experiments to determine the potential of natural and anthropogenic sources to contribute releasable organically bound Cu to the bottom waters of Puget Sound. Remobilization of Cu, at depth, as a result of discharge of primary effluent, appears to be more significant than remobilization from naturally occurring organic matter or diffusion from the sediments.

Concentrations of both natural and anthropogenic hydrocarbons on settling particles differ from those on suspended particles in the estuarine water column. Previous studies at PMEL showed that the major source of hydrocarbons to the sediments was the particles settling from surface waters. Results of a new study comparing hydrocarbon fluxes with fluxes of settling particles fractionated by size and density suggested specific hydrocarbon-particle associations that govern the flux of hydrocarbons to the sediments. These associations seem to be implicated in differential transport and selective sedimentation of particulate hydrocarbons, determining their horizontal distribution in sediments. They also are probably important in differential bioturbation, thus determining the vertical distribution of hydrocarbons in the sediment column.

We examined such associations in the distribution of polycyclic aromatic hydrocarbons (PAHs). PAHs are found worldwide in estuarine sediments. Their relative insolubility in water and resistance to degradation make them excellent sedimentary markers for land use changes, transport processes, and dating in an estuary. Ten cores from Puget Sound, Washington, were dated by ^{210}Pb and analyzed for combustion-derived PAHs and retene (a naturally occurring PAH found in coal and wood). Plots of date vs. PAH concentration showed a distinct PAH concentration peak for each core corresponding to ^{210}Pb dates circa 1940; plots of date vs. retene concentration also showed peaks corresponding to ^{210}Pb dates ranging between 1880 and 1925. The preliminary results suggest that particles to which ^{210}Pb binds are different from those to which some hydrocarbons attach, calling into question one of the fundamental assumptions of radionuclide dating of sediment horizons.

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Modeling

PMEL scientists helped organize and participated in a Workshop on Modeling Physical Oceanography of Puget Sound held 4-5 November 1987 at the NOAA Western Regional Center. The workshop brought together an international group of modelers and field oceanographers to discuss the state of knowledge of physical processes in the Puget Sound region, on-going and planned modeling efforts, and potential collaboration.

We used a turbulence closure model to investigate the effects of finite water depth on the magnitude and direction of the bottom stress due to steady barotropic currents. Accurate estimates of bottom stress are important in studies of current dynamics and transport of sediment and particulate-borne pollutants. The results show stress maxima 15% to 19% above deep-water values and angular deviations at the maxima 8° greater than those in deep water. A set of computationally efficient formulas have been fitted to the model results for interpretation and use in numerical models.

Formulas for suspended sediment flux were derived for the vertically integrated flux of suspended sediment from the classical log-velocity and Rouse-concentration profiles. The formulas, which closely match results from closure models, indicate that the flux is particularly sensitive to the ratio of settling velocity to friction velocity (square root of the kinetic bottom stress). In the slow-settling regime the flux varies inversely with the ratio but is much more sensitive in the fast-settling regime. The flux is also proportional to the erosion rate, which increases rapidly with increasing bottom stress.

We completed a channel tide model for Puget Sound. Tuned to observed distributions of the M2 tide, the model provides detailed distributions of tides and cross-sectionally averaged tidal currents as well as estimates of tidal prisms and dissipation for this complicated network of channels and embayments. There is good agreement between the observed distributions of tides throughout the system, primarily because the linear dynamics underlying the model dominate the tidal processes in Puget Sound and because the model resolves the complex topography of the system. There is also relatively good agreement of the averaged tidal currents at the few sections where detailed current observations are available even though the observed tidal currents often show major variations both across channels and with depth. The model shows a resonance somewhat below the M4 frequency that is relatively weak due to frictional dissipation concentrated mainly in the high-velocity channels.

The initial version of a laterally averaged model of Puget Sound showed good qualitative results. The salient features of currents and circulation were well represented. An increase in landward bottom transport in the interior of the Sound, occurring in the model, can only be the result of the downwelling of water in the vicinity of the Admiralty Inlet-main basin nexus; such a downwelling feature of circulation has long been recognized in the field data. A southward circulation over the entire water column in East Passage, shown by observations, can be reproduced in the model by imposing a northerly pressure gradient on the flow in Colvos Passage. Better geometric and bathymetric definition of the Sound is now being coded into the model to improve results quantitatively.

The laterally averaged hydrodynamic model provided current fields for a preliminary model of the distribution and transport of suspended solids in Puget Sound. The model simulates particle movement over the length and depths of the main basin and Admiralty Inlet, and over a 14-day period centered about an intrusion event. The model is required to have both small and large particles in the upper water column. The more rapidly settling large particles, thought to be macroaggregates, scavenge the more slowly settling fine particles as they fall vertically through the water column. With this process in the model, the calculated suspended solid distributions show the general features of the suspended particulate data, e.g., a middle-depth minimum down the axis of the main basin, but rapid vertical transport of fine particles is also allowed. The model poses a number of questions about particle sources and populations that will find answers only through additional field measurements and analysis of several existing data sets.

Puget Sound consists of a series of deep, stratified reaches separated by shallower sills and junctions where the mixing between water masses occurs and most of the rivers enter. On an annual time scale the transport of water and salt in each reach can be modeled as a steady two-layer advective flow. These flows intermingle in turbulent mixing zones where the flow from any incoming layer can be split into two parts: an efflux fraction that continues on into the next reach and a reflux fraction that recirculates into its original reach. During the past year we determined the efflux-reflux fractions for the mixing zones between the nine principal reaches in the Strait of Juan de Fuca-Puget Sound system.

Plans FY 1989

LONG-RANGE-EFFECTS RESEARCH

- Model the vertical distribution of particulate Mn in Puget Sound, using the results of the FY 1988 Mn precipitation experiments.

- Apply the results of the FY 1988 Cu remobilization experiments to a bottom layer box model of central Puget Sound and to the reflux model.

- Characterize the nature of Cu-organic interactions in Puget Sound during the FY 1989 field season.

- Extend the Puget Sound tides research to long-term sea level fluctuations and internal tides.

- Develop a steady low-resolution model of trace metal dynamics in stratified estuaries.

- Describe wind effects on flow through a cross section of a fjord.

- Complete code development of the laterally averaged hydrodynamic model of Puget Sound.

- Continue development of models concerned with the vertical transport of fine suspended solids by macroaggregate scavenging.

- Develop and implement a plan for using quasi-conservative tracers in testing the efflux-reflux model.

JIMAR

The Joint Institute for Marine and Atmospheric Research (JIMAR), located at the University of Hawaii, was formed in 1977, under a Memorandum of Understanding between the National Oceanic and Atmospheric Administration (NOAA) and the University of Hawaii. The principal research interests of JIMAR have been equatorial oceanography, climate, and tsunamis. A new interest in fisheries oceanography was added in FY 1988.

Accomplishments FY 1988

EQUATORIAL OCEANOGRAPHY

Western Equatorial Pacific Ocean Circulation Study (WEPOCS)

WEPOCS is a joint U.S.-Australian program to study the distribution of watermass properties and circulation in the near-equatorial region north of Papua, New Guinea. Among other objectives, WEPOCS aims to describe the effects of the northwest monsoon on the upper ocean circulation in this region.

The third U.S. WEPOCS expedition took place in the near-equatorial region north of Papua and near the Philippines during June and July 1988. The hydrographic conditions observed compared well with observations during WEPOCS I (July 1985) and II (February 1986), and intensive observations were obtained of the Mindanao Current and the Mindanao coastal circulation in the Celebes Sea.

The analysis of data sets from WEPOCS I and II has concentrated on a complete description of the mean circulation based on an isentropic analysis of the hydrographic data. We are assessing the influence of the monsoon on the circulation of the WEPOCS region through comparison of the water mass distributions during the two cruises and through analysis of the regional response of sea level.

Sea level, wind, and current data collected between WEPOCS I and II have been analyzed using an empirical orthogonal function. The analysis shows that sea level is influenced by the large-scale winds in the western Pacific, but there is structure associated with more local dynamics such as current flow through Vitiaz Strait, and the New Guinea Coastal Undercurrent.

Tropical Oceans and Global Atmosphere (TOGA)

TOGA's Coupled Ocean-Atmosphere Response Experiment (COARE) focuses on the strong air-sea interaction that occurs in the "warm pool" region of the equatorial western Pacific and

attempts to gain a better understanding of the processes that appear to be important during the development of ENSO episodes in that region, especially the role of intermittent strong westerly winds in mixing the upper ocean and moving the warm waters eastward. Analysis of historical data and concerted modeling efforts have begun as preliminary steps of the experiment.

United States-Peoples' Republic of China Cruises III and IV were successfully completed in the western Pacific; nearly continuous acoustic Doppler current profiler (ADCP) data were collected. Considerable progress has been made in upgrading the hardware and software used for this continuing collaborative research.

Acoustic Doppler Current Profiler (ADCP)

ADCP data from WEPOCS I were processed and documented, the Mindanao Current was extensively mapped, and current profiles were made along the track of the WEPOCS III cruise.

Analysis of the Pacific Equatorial Ocean Dynamics (PEQUOD) current profiles from the central equatorial Pacific has concluded, leading to the discovery of three currents below 1500 m that may be important parts of the general ocean circulation. A vertical mode analysis of the profiles has shown a clear dynamic scale separation in the upper ocean, in which the smaller scales are less variable than the larger scales.

Line Islands Array

The Line Islands Array consists of subsurface pressure gauges at four of the Line Islands-- Palmyra, Fanning, Jarvis, and Malden Islands, plus three inverted echo sounders deployed on the sea floor at 6°, 8°, and 10°N along 162°W. Extending from 4°S to 10°N, the array is designed to measure sea level variations on time scales from hours to years. No cruise was conducted in FY 1988 because of the 16-month array maintenance. Data from the third Line Islands Array cruise were processed, along with considerable analysis effort. Intercalibrations between echo sounder and subsurface pressure gauge data sets were completed.

Pacific Sea Level Network and Tropical Oceans and Global Atmosphere (TOGA) Sea Level Center

Three new satellite stations were installed and two existing stations rebuilt, making the network 29 stations in 17 countries. Nineteen of the stations report via satellite. All but five stations had complete data recovery during the year.

The stations are also part of the Global Sea Level Observing System (GLOSS), and data from the network are used to publish monthly maps of sea level through the International Global Ocean Services System (IGOSS). The network forms a cornerstone in the planning of a sea level network for the World Ocean Circulation Experiment (WOCE) and provides ground truth for the

calibration and verification of satellite altimetry for the GEOSAT and TOPEX (Topographic Experiment) missions.

IGOSS Sea Level Pilot Project (ISLPP)

The purpose of the project is to make monthly mean sea level data available in a timely fashion and to generate products that are valuable for the scientific analysis of climate-related processes. The data are used to publish monthly sea level maps, corrected for atmospheric pressure beginning in 1988.

In addition, an index of upper-layer volume for the equatorial Pacific, valuable for ENSO studies, is generated and published quarterly. An update of indices for the equatorial currents in the Pacific, which will be published annually, was included with the January map.

CLIMATE RESEARCH

El Niño-Southern Oscillation (ENSO)

Research focused on the synoptics of the equatorial western Pacific to evaluate the hypothesis that westerly wind bursts in this region may initiate and maintain El Niño, although the existence of such precursors has yet to be firmly established. It was shown that east Asian middle-latitude forcing could initiate westerly wind bursts in the equatorial western Pacific. The possibility that the well-known quasi-periodic nature of the ENSO could be reproduced from parametric time series models was assessed. Results indicate that the two optimal models produce a dominant spectral peak in the range between 3 and 4 years and small power at high frequencies, features consistent with those obtained from a conventional frequency-domain approach.

A study was conducted concerning Hawaiian drought and the Southern Oscillation (SO). We found that major drought winters in the Islands were preceded by a persistently low phase of the SO starting in March of the preceding year. Results of scatter diagrams also suggest that changes of the SO in summer lead corresponding changes of rainfall by 2-3 seasons.

Modeling and Analysis

A simple model of equatorial low-frequency motion was constructed to study the stability of the equatorial atmosphere in the presence of quasi-zonal, low-frequency disturbances. The model demonstrates that unstable interaction of boundary layer friction-induced moisture convergence with condensational heating could cause planetary-scale responses resulting in an asymmetric baroclinic structure having the largest flow field amplitude in the upper atmosphere.

A vertically continuous model describing two-dimensional equatorial motion confirmed this unstable interaction mechanism. Use of the model for analysis of moist Kelvin waves revealed

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that eddy energy is mainly generated in the surface convergence phase, which does not agree with the evaporation-wind feedback theory.

TSUNAMI RESEARCH

Two tide gauges were deployed in Hilo. A short course was again taught for the Army Corps of Engineers (including Civil Defense people) on post-tsunami run-up assessment and mapping.

Numerical modeling of the Shumagin seismic gap continued, using a nonlinear, shallow-water program to study the Kowalik and Murty model of the Gulf of Alaska along the Aleutian Islands. In the first study we observed, as Kowalik and Murty did, that the tsunami energy was strongly directed south toward Hawaii.

FISHERIES OCEANOGRAPHY

Optimal estimates were made of ocean current fields by means of objective analysis modeling of temperature profiles combined with temperature-salinity relationships from one survey around Johnston Island and three around Oahu in association with ichthyoplankton surveys. The goal is to interpret the distribution of larval fishes relative to the island in light of geostrophic current patterns. We found an expected general pattern of westward flow and the presence of a mesoscale cyclonic eddy on the north side of Johnston Island. Associated with the eddy is an eastward return flow west of the island and a stagnant region northwest of the island. The Johnston Island area contains unusually high densities of island-associated larval fishes in the 50-100 m stratum and the current patterns may have a pronounced effect upon larval recruitment and population maintenance.

A workshop, sponsored by JIMAR, was convened by the National Marine Fisheries Service (NMFS) at its Honolulu laboratory in May to review scientific understanding of the physical and biological factors and processes that affect rates of squid entanglement in driftnets, and to explore strategies for collaborative research to improve the understanding of driftnet entanglement problems in the North Pacific Transition Zone. A framework for a strategic plan was developed to provide guidance to the Squid Entanglement Task Force in preparation of a detailed set of research options and operating plans to achieve the following objectives: (1) to assess the effects of the incidental mortalities on the marine resources of the United States and on the benefits derived from them, and (2) to develop and evaluate management options for mitigation of the effects.

Plans FY 1989

EQUATORIAL OCEANOGRAPHY

- Analysis of the WEPOCS I and II data sets will continue, to assess the influence of the monsoon on the circulation of the WEPOCS region, to compare near-surface pressure gradients

across- and along-channel in the Vitiaz Strait with moored current measurements made by the Australians, and to study the role of mixing processes in the circulation of the region.

- The data from the WEPOCS III expedition are being processed, and much of FY 1989 will be required to finalize the data sets.

- A Science Working Group will be formed to develop and implement COARE.

- Two U.S.-P.R.C. TOGA cruises are planned, and the processing of the ADCP data will be carried out at sea on these cruises.

- Proposals have been submitted to work with RD Instruments in testing its present and new profilers.

- A program is being developed for observing the Mindanao Current over a 2-year period.

- The fourth of five cruises under the Line Islands Array program will be conducted in November 1988 for the purpose of maintaining the observing array of pressure gauges, inverted echo sounders, and tide gauges.

- The TOGA Sea Level Center will continue its current operations and will continue to generate monthly sea level maps.

- The Hawaii Ocean Time-series (HOT) project is designed to provide 5 years of physical, chemical, and biological oceanographic measurements from a deep-ocean site 100 km north of Oahu, for the purposes of observing climatological trends and assessing the representativeness of the observations made during the 5-year WOCE and GOFS programs. Monthly cruises to collect hydrographic measurements to provide a description of the mid-gyre variations of the Pacific Ocean will begin in October 1988.

CLIMATE RESEARCH

- Investigations of the origins and evolution of westerly wind bursts and analysis of the wind field of the tropical Pacific will continue, with emphasis on analysis strategies for the improvement of operational wind products.

- The surface wind variability in the western Pacific and sea level variation in association with equatorial intraseasonal convective disturbances will be studied.

- A five-level regional mesoscale model will be developed; it will be based on Florida State University's model.

TSUNAMI RESEARCH

- Numerical model studies on tsunami source mechanisms will continue, using both shallow-water and three-dimensional codes.

- Available data will be gathered, and the tsunami inundation-evacuation project will be refined according to a recently awarded contract with the State Civil Defense Agency.

- Publication of the *Tsunami Journal* will continue.

FISHERIES OCEANOGRAPHY

- High-resolution, vertically stratified ichthyoplankton data from around Oahu will be analyzed for plankton distribution relative to geostrophic current patterns.

- Two cruises to Southeast Hancock Seamount are planned for sampling. A current meter string will also be deployed for 4 months. This will allow comparison of current meter measurements with the ADCP-derived current data.

JISAO

The Joint Institute for Study of the Atmosphere and Ocean (JISAO) was established to foster collaboration between NOAA and the University of Washington. JISAO serves as a vehicle for funding grants and postdoctoral Fellows, supporting collaborative research between NOAA and University scientists. During the past few years, JISAO has emphasized three core research areas: climate, environmental chemistry, and estuaries.

JISAO's climate research has tended to focus on two main themes: large-scale atmosphere-ocean interaction in the tropics and planetary-scale wave-mean flow interaction. JISAO has been active in University and NOAA efforts to direct interdisciplinary research toward an understanding of the global climate system and its sensitivity to human activities. The new Experimental Climate Forecast Center within JISAO was established for this purpose.

The main research themes in environmental chemistry include marine aspects of the carbon dioxide problem and chemical processes involving the deposition of heavy metals. The former theme is closely related to climate research and the latter to estuarine research. Recently, JISAO's chemistry research has broadened in scope to include other biogeochemical cycles of interest for global climate. Of particular interest is the chemistry of sulfur and its influence on cloud condensation nuclei and the cycles that involve long-lived radiatively interactive trace species such as nitrous oxide and methane.

Accomplishments FY 1988

A study was completed that supports the use of doubly periodic models to examine eddy heat fluxes in fully turbulent baroclinic flows. The resulting two-layer model is expected to be an inexpensive and reliable tool for numerical investigations of parameterization theories used in climate research. Extensive numerical experiments have isolated the quasi-geostrophic regime that supports persistent, spatially organized storm tracks.

An investigation of mechanisms of oscillations of coupled ocean-atmosphere models (1) demonstrated that the Cane-Zebiak ENSO cycle is distinct from the mechanism responsible for the oscillating behavior in several other coupled models, (2) determined conditions that govern the selection of the oscillation mechanism, and (3) developed a simple model that captures the essence of the oscillation mechanism.

Work was completed on (1) the influence of the basic state and ocean geometry on interannual variability of the tropical atmosphere/ocean system, (2) the role of off-equatorial oceanic Rossby waves during ENSO, and (3) the interannual variability in a suite of tropical ocean-atmosphere models.

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Development was completed on the Electron Capture Sulfur Detector, a new instrument that precisely measures oceanic and atmospheric sulfur compound levels. This instrument is used to determine the influence of dimethyl-sulfide released by marine organisms upon cloud condensation.

In support of a meteorological experiment entitled OCEAN STORMS, analysis is under way on (1) a comparison of observations of a developing comma cloud with a numerical weather prediction model, (2) the development of a polar low, and (3) the stratosphere-troposphere exchange at a cold front.

The following student research projects continued: (1) tropical wind variability and the modeled ocean response to tropical surface wind stress variability, (2) the dynamic comparison of surface wind products for the Equatorial Pacific, (3) the annual variation of temperature in the upper tropical Pacific Ocean, (4) the dynamics of wind flow through Shelikof Strait, (5) analysis of cloud droplets by aircraft using a Counterflow Virtual Impactor, and (6) the construction of a two-dimensional model of the equatorial undercurrent in a stratified environment.

JISAO Senior Fellows were involved in scientific planning for NOAA's Climate and Global Change Program. The planning document ("The Role of the Ocean in NOAA's Program, 'Climate and Global Change'") details the scientific oceanographic problems that need to be solved in order to make predictions on decadal to centennial time scales. This report is expected to form the scientific basis for implementing the oceanographic portion of the Climate and Global Change Program.

JISAO supported a Distinguished Visitor (its first) from Woods Hole Oceanographic Institution in February 1988. The Visitor's research interests include problems on the equatorial undercurrent in the ocean and the equilibrium of finite amplitude baroclinic waves in the atmosphere. JISAO also invited a number of scientific visitors (domestic and foreign) to give seminars and interact with faculty, students, and PMEL scientists during the 1987 General Assembly of the International Union of Geodesy and Geophysics (held in Vancouver, B.C.). In addition, many of the JISAO affiliated scientists and students attended the conference on Waves and Stability sponsored by the American Meterological Society.

Plans FY 1989

- Work with NOAA to develop an expanded program to address scientific issues relating to global climate change.

- Establish a climate modeling capability to serve as a focus for research on coupled atmosphere-ocean interaction and biogeochemical cycles.

- Continue research on the predictability of ENSO, the effects of cloud radiation feedback on the coupled ocean-atmosphere system, and the dynamics and the maintenance of the Intertropical Convergence Zones in a General Circulation Model.

- Assess the mass flux from the stratosphere into the troposphere in extratropical cyclones.

- Continue a vigorous visitor and seminar program.

CIMRS

The Cooperative Institute for Marine Resources Studies (CIMRS) was established in 1982 to foster collaborative research between NOAA and Oregon State University in the areas of oceanography, fisheries, aquaculture and other marine-related fields and to serve as a center at which researchers may work on problems of mutual interest relating to the living and non-living components of the marine and estuarine environment and their interrelationships. Oregon State University is currently involved in research efforts that parallel NOAA/PMEL's VENTS Program objectives in the area of assessing the effect of spreading center hydrothermal vents on the marine environment. CIMRS often serves as a vehicle for funding grants which support collaborative research efforts between NOAA and University scientists. This annual report addresses only the collaborative efforts between CIMRS and NOAA/PMEL's VENTS Program.

In FY 1988, NOAA, through CIMRS, funded related research on radiochemical studies in hydrothermal samples from the Juan de Fuca Ridge. The purpose of this research is to determine the time that hydrothermal deposits were initially emplaced, their rate of accumulation, the length of time the hydrothermal fluid resided in the crust before the deposits were formed, and to investigate the scavenging processes occurring in the dispersing hydrothermal plume.

Six CIMRS research assistants contribute directly to the VENTS Program in various components of computer programming, analysis of side-scan sonar and photographic data of seafloor features from the Juan de Fuca Ridge system.

Accomplishments FY 1988

- Developed a FORTRAN subroutine which allows iterative, least-squares fitting of discrete, observational data such as seafloor bottom data by a nonlinear function. Use of this technique will allow the development of complex numerical models of natural systems.

- Developed a computer algorithm to smooth towed camera navigation data (side-scan sonar) using a least-squares cubic spline. In the testing stage is an iterative method for nonlinear surface fitting with the eventual objective of obtaining statistical information from navigated sidescan images that will allow classification of geological features on the seafloor.

PMEL STAFF

OFFICE OF THE DIRECTOR
Eddie N. Bernard, Director
James R. Holbrook, Deputy Director
LCDR Terry D. Jackson, Associate Director

Bernard, Eddie N.	Director
Holbrook, James R.	Supervisory Oceanographer
Jackson, Terry D., LCDR	NOAA Corps
Roper, Ridelle A.*	Secretary (Typing)
Wilson, Belle	Secretary (Typing)

TECHNICAL AND ADMINISTRATIVE SUPPORT
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Anderson, James W.	Photographer
Collins, Beverly J.	Budget Assistant
Cooke, Florence K.	Travel Clerk
Curl, Virginia M.	Illustrator
Elkins, Gayle L.	Motor Vehicle Operator
Loitsch, Cynthia L.	Program Support Manager
Perry, Richard M.	Motor Vehicle Operator
Register, Joy G.*	Illustrator (Scientific)
Smith, Claudia J.	Photographer
Snyder, Susan	Program Support Assistant
Thomasson, Norma H.	Support Services Supervisor
Taylor, Stashia	Clerk-Typist
Vose, Virginia	Computer Clerk
Whitney, Ryan L.	Computer Operator

COMPUTER SUPPORT
Paul Lu, Computer Manager

Angkico, Susana L.	Computer Programmer
Barzel, Ronald	Communications Specialist
Bathurst, William	Computer Programmer
Beard, Emily, LTJG	NOAA Corps
Bishop, Richard L.*	Computer Programmer
Borg-Breen, David	Computer Systems Programmer
Kay, Sharon	Computer Aid
Lu, Paul	Computer Specialist
McCarty, Laura C.	Computer Programmer
McKenna, Rory*	Computer Clerk

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Renton, Mark	JISAO/Research Scientist
Richards, Russel	Computer Equipment Analyst
Tanigawa, Dale	Computer Operator
Vance, Tiffany C.	Computer Programmer
Walker, Andrew D.	Computer Operator

ENGINEERING DEVELOPMENT DIVISION
Hugh B. Milburn, Division Leader

Delizo, Stan W.	Engineering Technician
Gable, James R.	Electronics Technician
Holzer, Dennis E.	Instrument Maker
Jackson, Thomas G.	Electronics Technician
Mader, Floyd W.	Electronics Technician
McLain, Patrick D.	Electronics Engineer
Milburn, Hugh B.	Supervisory General Engineer
Miller, Hendrick	Engineering Technician
Nakamura, Alex I.	Electronics Engineer
Newman, Roy	Electronics Technician
Schattgen, Paul L., LTJG	NOAA Corps
Shanley, John C.	Engineering Aid
Stapp, Michael F.	Electronics Technician

MARINE ASSESSMENT RESEARCH DIVISION
Herbert C. Curl, Jr., Division Leader

Cannon, Glenn A.	Oceanographer
Cokelet, Edward D.	Oceanographer
Curl, Herbert C., Jr.	Supervisory Oceanographer
Froberg, Sharon L.	Physical Science Technician
Herzog, Carolyn	Secretary
Lavelle, John W.	Oceanographer
Lytle, Lisa	Physical Science Aid
Mofjeld, Harold O.	Oceanographer
Murphy, Paulette P.	Chemist
Pashinski, David J.	Oceanographer
Paulson, Anthony J.	Oceanographer
Podber, David*	Mathematician

MARINE RESOURCES RESEARCH DIVISION
Stephen R. Hammond, Division Leader

Appelgate, Bruce	CIMRS/Graduate Student
Baker, Edward T.	Oceanographer
Burger, Richard S.*	Physical Science Technician
Dziak, Robert	CIMRS/Research Assistant
Eastham, Robin	CIMRS/Clerk Typist
Embley, Robert W.	Geophysicist

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Feely, Richard A.	Oceanographer
Fox, Christopher	Physical Scientist
Geiselman, Terri L.	Oceanographer
Gendron, James F.	Chemist
Hammond, Stephen R.	Supervisory Oceanographer
Hanneman, Susan	CIMRS/Research Assistant
Jones, Frederick J., CDR	NOAA Corps
Lau, Andy	CIMRS/Research Assistant
Lebon, Geoffrey J., LTJG	NOAA Corps
Massoth, Gary J.	Oceanographer
Murphy, Kim	CIMRS/Research Assistant
Nitchman, Catherine, LTJG	NOAA Corps
Restrepo, Maria	CIMRS/Research Assistant
Roberts, Marilyn F.	Physical Science Technician
Rodarmel, Kimberly	Secretary
Roe, Kevin K.	Oceanographer
Salem, Brian	Oceanographer
Seem, Dennis, LT	NOAA Corps
Tennant, David A.	Oceanographer
Waddell, Jessica	CIMRS/Administrative Assistant
Walker, Sharon L.	Oceanographer

MARINE SERVICES RESEARCH DIVISION
James E. Overland, Division Leader

Aagaard, Knut	Oceanographer
Blake, Wade J., LTJG	NOAA Corps
Bond, Nicholas	JISAO/Postdoctorate
Darnall, Clark	JISAO/Research Engineer
DeWitt, Carol	Physical Science Technician
Dickson, Karen*	Secretary (Typing)
Eble, Marie	Oceanographer
Galasso, George, LTJG*	NOAA Corps
Gonzalez, Frank I.	Oceanographer
Gray, Judith G.	Meteorologist
Jenkins, Nora*	Computer Programmer
Kachel, David G.	Computer Programmer
Lackmann, Gary M.	JISAO/Research Assistant
Long, Virginia L.	Physical Science Technician
Macklin, Stewart A.	Meteorologist
Mattens, David M., LTJG	NOAA Corps
Overland, James E.	Supervisory Oceanographer
Parker, William J.	Field Operations Specialist
Pease, Carol H.	Oceanographer
Proctor, Peter D.	Physical Science Aid
Reed, Ronald K.	Oceanographer
Roach, Andrew	Oceanographer
Salo, Sigrid	Oceanographer
Saucier, Suzanne	Clerk-Typist
Schumacher, James D.	Oceanographer

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Turet, Philip   Statistician
Walter, Bernard A.   Physical Scientist

OCEAN CLIMATE RESEARCH DIVISION
Bruce A. Taft, Division Leader

Bates, Timothy S.   Research Chemist
Coho, Carolyn S., ENS   NOAA Corps
Cole, Richard D.   Physical Science Technician
Davison, Jerry C.   JISAO/Research Scientist
Freitag, Howard P.   Oceanographer
Gammon, Richard   Supervisory Chemist
Gearin, Linda   Oceanographer
Giese, Benjamin S.   JISAO/Research Assistant
Gifford, Sue E.   Secretary (Typing)
Hankin, Steven   Computer Programmer
Harrison, Don E.   Oceanographer
Hayes, Stanley P.   Supervisory Oceanographer
Hirst, Susan J.*   JISAO/Research Scientist
Johnson, James E.   JISAO/Research Scientist
Kelly, Kimberly C.   Oceanographer
Kessler, William S.   JISAO/Research Assistant
Larsen, Jimmy C.   Oceanographer
Lee, Daniel   JISAO/Scientific Programmer
Lynch, Jean*   Oceanographer
Mangum, Linda J.   Oceanographer
Manke, Ansley B.   Computer Programmer
McCarty, Marguerite   JISAO/Computer Programmer
McPhaden, Michael   Oceanographer
McTaggart, Kristine   JISAO/Research Assistant
Meenen, Marilyn   Clerk-Typist
Menzia, Fred   JISAO/Research Scientist
Moore, Ben A.   Electronics Technician
Paul, Daniel*   Oceanographer
Pullen, Patricia E.   Oceanographer
Sarachik, Edward S.*   Oceanographer
Shepherd, Andrew J.   Electronics Technician
Soreide, Nancy N.   Computer Programmer
Taft, Bruce A.   Supervisory Oceanographer
Verschell, Mark A.   JISAO/Scientific Programmer
Wilson, Clifford C., LTJG   NOAA Corps
Wisegarver, David P.   Chemist

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* No longer affiliated with PMEL

PMEL SEMINARS

Dates	Name and Affiliation	Seminar Topic
1987		
10 September	Dr. Joel Picaut ORSTROM Noumea, New Caledonia	Use of the geostrophic relation to monitor the 1979-1985 equatorial Pacific currents
20 October	Dr. John Harvey University of East Anglia United Kingdom	The transport and mixing of water masses by eddies: including some results of the Tourbillon Experiment
17 November	Dr. Eric Johnson Scripps Institution of Oceanography La Jolla, CA	Characteristics of mean current instabilities in the upper equatorial Pacific determined from Doppler acoustic velocity and CTD density sections
29 December	Dr. Stuart Godfrey CSIRO Hobart, Australia	Global calculation of the Sverdrup transport
1988		
4 February	Dr. Bruce Howe Applied Physics Laboratory University of Washington	Ocean acoustic tomography: mesoscale velocity
18 February	Dr. Wen-Sen Chu Dept. of Civil Engineering University of Washington	Modeling tides and tidal transport in central Puget Sound
1 March	Dr. Anthony Clarke University of Hawaii Honolulu, HI	Light absorbing aerosols in the remote environment
4 March	Dr. Margaret Leinen University of Rhode Island Kingston, RI	Late Pleistocene variations in hydro-thermal sedimentation in the Juan de Fuca region

1 April	Dr. Michael Perfit University of Florida Gainesville, FL	Petrologic and geochemical constraints on origin of magmas and massive sulfides along the eastern Galápagos Rift
12 April	Dr. David Griffin University of British Columbia Vancouver, B.C., Canada	The density tide
26 April	Dr. Alan Mearns Coastal and Estuarine Assessment Branch, NOAA/NOS/OAD Rockville, MD	Marine life and oceanography along the U.S. West Coast
10 May	Dr. James K.B. Bishop Lamont-Doherty Geological Observatory Columbia University Palisades, NY	Global patterns of particulate matter chemistry and flux

23 May	Dr. Horst Böttger
	Meteorological Division of the
	  European Centre for Medium-
	  Range Weather Forecasts,
	Reading, England
		Operation and general information
		on the European Centre for Medium-
		Range Weather Forecasts

24 May	Dr. Russ McDuff University of Washington	Some effects of hydrothermal vent chemistry on plume behavior
1 June	Dr. V.K. Gusiakov Computer Center Novosibirsk, USSR	Tsunami research in the Soviet Union
1 June	Dr. Taro Takahashi Lamont-Doherty Geological Observatory Columbia University Palisades, NY	Air-sea CO_2 exchange of the global oceans
2 June	Dr. C.S. Wong Institute of Ocean Sciences Sidney, B.C., Canada	1986-87 El Niño and pCO_2/nutrient distributions in the equatorial Pacific

| 7 June | Dr. Jim Todd
Oceanic and Atmospheric
  Research, NOAA
Rockville, MD | Exchange rates in coastal oceanic waters
using Ra-224 |
| 27 July | Dr. Hermann Gucinski
Ann Arundel Community College
Arnold, MD | The sea surface microlayer: biophysical
interactions of environmental
significance |

JISAO SEMINARS

Date	Name and Affiliation	Seminar Topic
1987		
6 August	Dr. Heinrich Quenzel University of Munich Munich, W. Germany	Potential of space-born backscatter lidar and a planned German space-shuttle experiment
	Dr. Theodore Shepherd Cambridge University Cambridge, U.K.	Implications and applications of nonlinear wave activity conservation
17 August	Dr. H. Tennekes Royal Netherlands Meteorological Institute The Netherlands	Why worry about predictability?
24 August	Dr. Isaac Held GFDL Princeton University Princeton, NJ	Intraseasonal tropical variability in an idealized GCM
	Dr. I.M. James University of Reading Reading, U.K.	Antarctica and the Southern Hemisphere circulation
	Dr. John C. Marshall Imperial College London, U.K.	Thermal equilibration of planetary waves
26 August	Dr. I.M. James University of Reading Reading, U.K.	Baroclinic instability in planetary atmospheres
2 September	Dr. Bruce Long Scripps Institution of Oceanography La Jolla, CA	The Lyapunov stability of steady ideal fluid flow

| 21 October | Dr. John Harvey
University of East Anglia
United Kingdom | The contribution of water mass analysis to understanding North American circulation |

1988

7 January	Dr. Tim Barnett Scripps Institution of Oceanography La Jolla, CA	Interaction of Asian snow cover, Asian monsoon and El Niño
27 January	Dr. Lynn Shay Naval Postgraduate School Monterey, CA	Vertical structure of the ocean current response to hurricanes
29 January	Dr. Ping Chang GFDL Princeton University Princeton, NJ	Oceanic adjustment in presence of mean currents: the role of discrete and continuous modes
5 February	Dr. Tim Palmer ECMWF Reading, U.K.	Medium and extended range prediction and the stability of the PNA mode
8 February	Dr. Tsuyoshi Nitta Meteorological Research Institute Tsukuba, Japan	Relationship between ENSO and climate anomalies over the western Pacific
19 February	Dr. Joseph Pedlosky Woods Hole Oceanographic Institution Woods Hole, MA	Nonlinear dynamics of unstable baroclinic waves
26 February	Dr. Yochanan Kushnir JISAO University of Washington	Low frequency variability in a 39-year 500-mb data record
7 March	Dr. Uwe Send Scripps Institution of Oceanography La Jolla, CA	Flow relaxations on the continental shelf

10 May	Dr. Yi-Hong Pan NOAA/NOS Observational Division Greenbelt, MD	Correlation analysis of the sea-surface temperature over the world oceans with those in the east equatorial Pacific based on the COADS data
19 May	Dr. Ignacio Galindo Dept. of Geophysics University of Mexico Mexico City, Mexico	ENSO effects along the Pacific coast of Mexico

JIMAR SEMINARS

Date	Name and Affiliation	Seminar Topic
1987		
9 October	Dr. Mark L. Morrissey Department of Meteorology University of Hawaii Honolulu, HI	Report on the Workshop on Low Frequency Oscillations in the Atmosphere held at NCAR, July 1987
16 October	Dr. Bin Wang Department of Meteorology University of Hawaii Honolulu, HI	Dynamics of the 40-50 day oscillation of the tropical atmosphere
10 November	Dr. J.M. Verstraete ORSTOM Institute Oceanographique Paris, France	The zonal and meridional pressure gradients in the equatorial Atlantic in response to the trade winds and African monsoon in 1983 and 1986
1988		
12 January	Dr. Mark Wimbush University of Rhode Island Narragansett, RI	Current and temperature fluctuations on southeast U.S. continental shelf
20 January	Dr. Bruce Taft PMEL/NOAA Seattle, WA	On monitoring the tropical Pacific geostrophic circulation by XBT lines and sea level
28 March	Dr. Ray Schmitt Department of Physical Oceanography Woods Hole Oceanographic Institution Woods Hole, MA	Salt fingers in the western tropical north Atlantic
14 April	Mr. Ben Giese PMEL/NOAA Seattle, WA	Modeling the oceanic response to a westerly wind burst

3 May	Dr. Raymond Pollard Institute for Oceanographic Sciences Wormley, Godalming United Kingdom	3-dimensional circulation at the oceanic front
5 May	Dr. Kelvin Richards Department of Oceanography The University of Southampton United Kingdom	Rotating flow over topography-flow separation and mixing
24 May	Ms. Jane Verall Institute of Ocean Studies Sydney, Australia	Application of pseudo random coding to acoustic signal analysis
15 July	Dr. Francis Ting W.M. Keck Laboratory of Hydraulics and Water Resources California Institute of Technology Pasadena, CA	Summary of doctoral dissertation on wave interactions with submarine trench in a density-stratified fluid
21 July	Dr. M. Kimberly Smith Mexican National Fisheries Institute Ciudad del Carmen, Campeche Mexico	Biology and management of the fisheries resources of Campeche Sound, Mexico
26 July	Dr. John Gulland Center of Environmental Technology Imperial College University of London London, England	Antarctic marine resources - exploration, protection, or management?
17 August	Dr. Julian McCreary Ocean Sciences Center Nova University Dania, FL	A hierarchy of models of coastal currents along eastern ocean boundaries
16 August	Dr. Greg Holland Bureau of Meteorology Research Center Melborne, Australia	Tropical cyclone motion

18 August

Dr. Allan Clarke
Department of Oceanography
Florida State University
Tallahassee, FL

Inertial wind path and sea surface temperature patterns near the Gulf of Tehuantepec and Gulf of Papagayo

PMEL PUBLICATIONS

AAGAARD, K. Some thoughts on the large-scale circulation of the Arctic Ocean. Preprints, Second Conference on Polar Meteorology and Oceanography, Madison, WI, March 29-31, 1988. American Meteorological Society, Boston, 1-3 (1988).

No abstract.

AAGAARD, K., C. DARNALL, A. Foldvik, M. Steg, and T. Tørresen. Fram Strait current measurements 1985-1986. Joint Data Report, University of Bergen Report No. 66/PMEL Report Contribution No. 1021, Bergen, Norway, 43 pp. (1988).

No abstract.

AAGAARD, K., C.H. PEASE, and S.A. SALO. Beaufort Sea mesoscale circulation study--preliminary results. NOAA TM ERL PMEL-82 (PB89-121693), 171 pp. (1988).

The Beaufort Sea Mesoscale Circulation Study was initiated in the autumn of 1986 and included measurements of currents, winds, and ice velocities, as well as observations of state variables and nutrient distributions in the ocean and state variables in the polar atmosphere, principally between Barrow and Demarcation Point along the American Beaufort Sea shelf. This report describes the preliminary results from observations made during the first year of the project, including current velocity results from meters recovered through the ice in April 1987, hydrographic and nutrient sections completed in October 1986 and April 1987, wind velocity, air pressure and temperature records recovered continuously through the end of 1987, ARGOS buoy tracks through 1987, and a representative sample of analyzed weather maps during the first year. Data collection continued through April 1988. The total data set is extraordinary in the temporal and spatial extent of its synoptic coverage, and in the variety of its constituent measurements. The data set is also extremely large, and its full reduction and analysis will provide an exceptional opportunity for improving our understanding of the shelf circulation and its forcing, as well as conditions important to the marine ecology of the area.

AAGAARD, K., S. SALO, and K. Krogslund. Beaufort Sea mesoscale circulation study: Hydrography helicopter operations, April, 1987. NOAA DR ERL PMEL-22 (PB88-203658), 25 pp. (1988).

No abstract.

Andreae, M.O., H. Berresheim, T.W. Andreae, M.A. Kritz, T.S. BATES, and J.T. Merrill. Vertical distribution of dimethylsulfide, sulfur dioxide, aerosol ions, and radon over the northeast Pacific Ocean. *Journal of Atmospheric Chemistry* 6:149-173 (1988).

Dimethylsulfide (DMS), sulfur dioxide (SO_2), methanesulfonate (MSA), nonsea-salt sulfate (nss-SO_4^{2-}), sodium (Na^+), ammonium (NH_4^+), and nitrate (NO_3^-) were determined in samples collected by aircraft over the open ocean in postfrontal maritime air masses off the northwest coast of the United States (3-12 May 1985). Measurements of radon daughter concentrations and isentropic trajectory calculations suggested that these air masses had been over the Pacific for 4-8 days since leaving the Asian continent. The DMS and MSA profiles showed very similar structures, with typical concentrations of 0.3-1.2 and 0.25-0.31 nmol m^{-3} (STP) respectively in the mixed layer, decreasing to 0.01-0.12 and 0.03-0.13 nmol m^{-3} (STP) at 3.6 km. These low atmospheric DMS concentrations are consistent with low levels of DMS measured in the surface waters of the northeastern Pacific during the study period. The atmospheric SO_2 concentrations always increased with altitude from <0.16-0.25 to 0.44-1.31 nmol m^{-3} (STP). The nonsea-salt sulfate (nss-SO_4^{2-}) concentrations decreased with altitude in the boundary layer and increased again in the free troposphere. These data suggest that, at least under the conditions prevailing during our flights, the production of SO_2 and nss-SO_4^{2-} from DMS oxidation was significant only within the boundary layer and that transport from Asia dominated the sulfur cycle in the free troposphere. The existence of a "sea-salt inversion layer" was reflected in the profiles of those aerosol components, e.g., Na^+ and NO_3^-, which were predominantly present as coarse particles. Our results show that long-range transport at mid-tropospheric levels plays an important role in determining the chemical composition of the atmosphere even in apparently "remote" northern hemispheric regions.

BAKER, E.T., H.B. MILBURN, and D.A. TENNANT. Field assessment of sediment trap efficiency under varying flow conditions. *Journal of Marine Research* 46:573-592 (1988).

Knowledge of the collection efficiency of sediment traps, particularly under conditions of varying current speed, is presently more a matter of hope than confidence. We report here on a field experiment designed to determine, for a particular trap geometry, the effect of current speed and particle fall velocity on the collection efficiency of a moored trap relative to the presumably unbiased efficiency of an identical drifting trap. The experiment was performed in a deep estuarine tidal passage where a smoothly varying unidirectional flow and a spatially homogenous particle population mimicked laboratory flume conditions. A multiple-sample sediment trap integrated to a current meter partitioned the mass flux collected by the moored trap into one of four chambers according to the following speed intervals: <12, 12-<30, 30-<50, and ≥50 cm/s. The magnitude and particle characteristics of the flux collected at <12 cm/s were indistinguishable from those simultaneously collected by drifting traps. At higher speeds, the relative efficiency of the moored trap ranged between 1% and 24% and the mean size and density of the trapped particles increased. These results support predictions based on laboratory studies that collection efficiency decreases with an increase in the trap Reynolds number or a decrease in particle fall velocity. The study demonstrates that consideration must be given to scaling both trap diameter and aspect ratio according to the

expected flow conditions, and that knowledge of flow conditions at the trap mouth is necessary to properly interpret the flux data.

Barnett, T.P., and R.W. PREISENDORFER. Origins and levels of monthly and seasonal forecast skill for United States surface air temperatures determined by canonical correlation analysis. *Monthly Weather Review* 115(9):1825-1850 (1987).

Statistical techniques have been used to study the ability of SLP, SST and a form of persistence to forecast cold/warm season air temperatures over the United States and to determine the space-time evolution of these fields that give rise to forecast skill. It was found that virtually all forecast skill was due to three climatological features: a decadal scale change in Northern Hemisphere temperature, ENSO-related phenomena, and the occurrence of two distinct short-lived, but large-scale, coherent structures in the atmospheric field of the Northern Hemisphere. The physical mechanisms responsible for the first two signals are currently unknown. One of the large-scale, coherent features seems largely independent of the ENSO phenomena, while the second is at least partially related to ENSO and may be part of a recently discovered global mode of SLP variation. Both features resemble various combinations of known teleconnection patterns. These large-scale coherent structures are essentially stationary patterns of SLP variation that grow in place over 2 to 3 months. The structures decay more rapidly, typically in 1 month, leading to a highly asymmetric temporal life cycle. The average forecast skills found in this study are generally low, except in January and February, and are always much lower than expected from studies of potential predictability. Increase in the average skills will require new information uncorrelated with any of the data used in this study and/or prediction schemes that are highly nonlinear. However, the concept of an average skill may be misleading. A forecast quality index is developed and it is shown that one can say in advance that some years will be highly predictable and others not. Use of the classical definition of "winter" in forecast work may not be advisable since each of the months that make up winter are largely uncorrelated and predicted by different atmospheric features.

BERNARD, E.N. (ed.). Proceedings of the International Tsunami Symposium, Vancouver, British Columbia, Canada, August 18-19, 1987. International Union of Geodesy and Geophysics, ERL Special Report (PB89-100895), 340 pp. (1988).

No abstract.

BERNARD, E.N., R.R. BEHN, G.T. Hebenstreit, F.I. GONZALEZ, P. Krumpe, J.F. Lander, E. Lorca, P.M. McManamon, and H.B. MILBURN. On mitigating rapid onset natural disasters: Project THRUST. *Eos, Transactions of the American Geophysical Union* 69(24):649-661 (1988).

Rapid onset natural hazards have claimed more than 2.8 million lives worldwide in the past 20 years. This category includes such events as earthquakes, landslides, hurricanes, tornados,

floods, volcanic eruptions, wildfires, and tsunamis. Effective hazard mitigation is particularly difficult in such cases, since the time available to issue warnings can be very short or even nonexistent. This paper presents the concept of a local warning system that exploits and integrates the existing technologies of risk evaluation, environmental measurement, and telecommunications. We describe Project THRUST, a successful implementation of this general, systematic approach to tsunamis. The general approach includes pre-event emergency planning, real-time hazard assessment, and rapid warning via satellite communication links.

BERNARD, E.N., R.R. BEHN, and H.B. MILBURN. A tsunami early warning system. Proceedings of the International Tsunami Symposium, Vancouver, British Columbia, Canada, August 18-19, 1987. International Union of Geodesy and Geophysics, ERL Special Report (PB89-100895), 276-290 (1988).

A pilot local ($\approx$100 km) tsunami warning system has been developed to deliver tsunami warning information within 2 minutes of earthquake origin time. Tsunami Hazards Reduction Utilizing Systems Technology (THRUST) system was installed in Valparaiso, Chile to evaluate its value in mitigating tsunami hazards in countries without regional warning systems. The satellite-linked system consists of a pre-tsunami preparedness program and real-time data collection and information dissemination instruments. To develop the preparedness program, an examination of past tsunami wave heights supplemented by numerical simulations of potential tsunamis provided the basis for evacuation areas in Valparaiso's emergency operations plan. Instruments used to collect geophysical data include an accelerometer to measure earthquake intensity and a water pressure gauge to measure tsunami activity. Once the acceleration threshold has been exceeded, a signal is transmitted that prompts the GOES satellite to automatically broadcast an alert message. Receivers in Valparaiso and other warning locations under the GOES communications coverage (Honolulu, Hawaii; Seattle, Washington; and Boulder, Colorado) continuously monitor the satellite for this alert message and take predetermined action once received. Cost for the essential THRUST equipment is about $15,000, exclusive of installation. Evaluation of the real-time equipment over a 1-year test revealed an average communications time of 1.6 minutes from accelerometer signal to printed message at the receiver site and an equipment reliability factor in excess of 90%. THRUST is an example of a systems approach to natural hazards mitigation management that blends new technologies with existing operations for the benefit of affected populations.

BOND, N.A., and R.G. Fleagle. Prefrontal and postfrontal boundary layer processes over the ocean. *Monthly Weather Review* 116(6):1257-1273 (1988).

Measurements taken during the Storm Transfer and Response Experiment (STREX) are used to analyze boundary layer structures and processes in North Pacific storms. Heat and moisture transfers at the surface and through the top of the boundary layer are evaluated for three cases with warm, southerly flow ahead of cold fronts and two cases of cooler, westerly and northern flow behind fronts. The prefrontal boundary layers are nearly neutrally stratified

and surface heat and moisture fluxes are small. Surface fluxes tend to be downward just ahead of the fronts and are of greater magnitude during stronger storms. Entrainment fluxes are the top of the prefrontal boundary layers are generally larger than surface fluxes and are the dominant sources of heating for the boundary layers. Entrainment rates determined from budgets compare well with laboratory studies of shear-driven entrainment. In the postfrontal cases, surface heat and moisture fluxes are the dominant sources of total heating within the boundary layers. Entrainment velocities are larger in postfrontal than prefrontal regions, but entrainment has only a small and positive net effect on the total heat content. In postfrontal transition layers the Richardson numbers are large, and entrainment is forced by turbulence generated by buoyancy in the surface layers and radiative and evaporative cooling from the tops of stratocumulus clouds. Cumulus-scale penetrative convection represents the major sink of boundary layer moisture for one case with a long atmospheric fetch over the ocean.

Businger, S., and B. WALTER. Comma cloud development and associated rapid cyclogenesis over the Gulf of Alaska: A case study using aircraft and operational data. *Monthly Weather Review* 116(5):1103-1123 (1988).

The NOAA P-3 aircraft was used to collect data in a genesis region for mesoscale comma clouds over the Gulf of Alaska. Aircraft measurements in the genesis region showed that rainbands with spacings of 65-75 km and orientations along the mean wind shear were present. Possible mechanisms for the formation of the rainbands, including conditional symmetric instability (CSI) and modified wave-CISK were investigated, but the data did not allow the formation of the rainbands to be conclusively ascribed to a particular mechanism. The existence of low static stability in the genesis region was also documented and its role in mesoscale comma-cloud development explored. Careful analysis of images from NOAA polar orbiter and GOES satellites together with synoptic analyses made it possible to trace the life cycles of several mesoscale comma clouds as the genesis region moved across the Gulf of Alaska. As the genesis region approached a preexisting polar frontal cloud band, a wave cyclone formed on the front and absorbed one of the comma clouds. The resulting cyclone central pressure dropped 25 mb in 12 hours. The intensity of this development was underestimated by operational forecast models.

CANNON, G.A. Flow variations through sections across Puget Sound. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 103-107 (1988).

Flow in the Puget Sound estuarine system is important in determining the fate of contaminants within the system. Research since the early 1970's has focused on determining circulation characteristics, space and time variations, and the dominant physical processes causing these variations. During the course of this research some of our earlier ideas have changed, and this paper presents a brief overview of our present understanding of the dominant physical processes affecting the Puget Sound system. Cross-channel observations of currents recently made at a few locations suggest residual fluxes about half those estimated earlier from midchannel observations. Variations in the residual circulation (tides removed)

are dominated by two physical processes. Wind effects account for about 50% of the residual energy, and density driven deep-water intrusions account for about 20%. The winds appear to have effects both near the surface and at middepths. Previous studies have shown that major bottom-water inflow events occur during neap tides when mixing over the sill is least and propagate along the main basin and into some side basins. New observations show the onset also may be the result of salinity variations across the sill caused by changes in the Strait of Juan de Fuca estuary which in turn may be partly caused by coastal storms.

COKELET, E.D., R.J. Stewart, and C.C. Ebbesmeyer. The annual mean transport and refluxing in Puget Sound. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 108-119 (1988).

No abstract.

CONWAY, T.J., P. Tans, L.S. WATERMAN, K.W. Thoning, K.A. Masarie, and R.H. GAMMON. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981-84. *Tellus* 40B:81-115 (1988).

The carbon dioxide concentration has been measured in air samples collected approximately once per week at 22 globally distributed sites during 1981-84. All samples were analyzed on the same non-dispersive infrared analyzer apparatus at the NOAA/GMCC laboratory in Boulder. The measured concentrations are directly traceable to the WMO primary CO_2 standards. Samples which do not contain well-mixed, regionally representative air or which have been contaminated during or subsequent to sampling, have been identified. The selected data have been analyzed using an objective curve fitting method which enables improved estimation of uncertainties associated with derived parameters. The latitudinal distribution of annual mean CO_2 concentration at the network sites shows significant interannual variability possibly related to the 1982-83 El Niño/Southern Oscillation event. No evidence was found for significant interannual variations or trends in the phase or amplitude of the seasonal cycle. Significant interannual and interstation variability in the CO_2 growth rate was observed. A growth rate minimum during 1982 was followed by a growth rate maximum in 1983, in association with the intense 1982-83 ENSO event. The mean global growth rate for 1981-84 was 1.22 ppm yr^{-1}.

Crecelius, E.A., and H.C. CURL, JR. Temporal trends of contamination recorded in sediments of Puget Sound. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 21-32 (1988).

No abstract.

CURL, H.C., JR. Assimilative capacity: A "discredited" idea whose time is yet to come. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 247-255 (1988).

No abstract.

CURL, H.C., JR., E.T. BAKER, T.S. BATES, G.A. CANNON, R.A. FEELY, T.L. GEISEL-MAN, M.F. LAMB, P.P. MURPHY, D.J. PASHINSKI, A.J. PAULSON, and D.A. TENNANT. Contaminant transport from Elliott and Commencement Bays. NOAA TM ERL PMEL-78 (PB88-219456), 136 pp. (1988).

Major sources of contamination to Puget Sound are concentrated in the urban embayments. Most of these contaminants are particulates or adhere to particles. If these particulates are dense, they tend to fall out of the water column near the source; thus analysis of the sediment within urban embayments can provide an indication of the level of contamination, and by proximity, of the probable source of that contamination. The question remains however, to what degree are contaminants transported, away from the original source, out of the embayment, and are carried into the main basin of the Sound. In other words, to what extent is incoming contamination localized, or Sound-wide in nature. In order to determine this we attempted to answer the following research questions: 1) What is the relative importance of the surface, fresh water plume versus the bottom resuspended (nepheloid layer)? 2) How much does transport vary seasonally, particularly as affected by winter runoff? 3) Is there loss to the bottom from the surface plume? 4) Are contaminants remobilized from the bottom sediments? During spring and summer 1985, and again in January 1986, the Pacific Marine Environmental Laboratory (PMEL) of NOAA made a series of observations designed to determine to what degree contaminants in Elliott and Commencement Bays could leave the bays and enter the main basin of Puget Sound. The approach employed in this study was to map the distributions of water properties (salinity, suspended particulate matter or SPM, and toxic trace metals and organics) during a period of high river runoff (April 4-5, 1985, Elliott and Commencement Bay) and during combined sewer overflow (CSO) events (January 8-9, 1986, Elliott Bay only) after heavy rainfall. Current meters and sediment traps were deployed in Elliott Bay south of the Pier 90 anchorage and in Commencement Bay in the outer, center of the bay. The current meters provide a continuous record of salinity, temperature, current speed and direction which allows a calculation of horizontal transport.

Ebbesmeyer, C.C., C.A. Coomes, J.M. Cox, G.A. CANNON, and D.E. Bretschneider. Decade-long regimes of a fjord basin's oceanography, hydrology, and climatology: Puget Sound, 1916-1987. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 50-57 (1988).

Data collected at eleven sites in the Pacific Northwest during 1916-1987 indicate that the flow pattern in Puget Sound's Main Basin oscillates between two regimes (I, II) each typically lasting a decade and having distinct oceanographic, hydrologic, and climatic characteristics.

EMBLEY, R.W., L.D. Kulm, G. MASSOTH, D. Abbott, and M. Holmes. Morphology, structure, and resource potential of the Blanco transform fault zone. Geology and Resource Potential of the Continental Margin of Western North America and Adjacent Ocean Basins--Beaufort Sea to Baja, California, D.W. Scholl, A. Grantz, and J.G. Vedder (eds.), Circum-Pacific Council for Energy and Mineral Resources, Earth Sciences Series, Vol. 6, 549-561 (1987).

A series of rhombohedral basins along the 350-km-long Blanco transport fault zone (BTFZ) are oceanic analogs to pull-apart basins along major divergent wrench fault systems on the continent. In plan view, the BTFZ is similar to the Gulf of California; a series of long strike-slip faults (as much as 100 km long) are separated by short extensional basins (<20 km) that have internal structures oriented at a large angle to the master faults. In the Blanco region, continual reorientation of the transform fault in response to changes in plate motion during the past few million years provides a mechanism for the formation of these basins. A series of back-tilted, inward-facing fault blocks covered with uplifted turbidite beds brackets the largest of the depressions (Cascadia), which may be a sea-floor-spreading center. Deformed Holocene and Pleistocene turbidite sequences are present within the depression, and there is substantive morphologic and sedimentologic evidence of rapid Holocene subsidence of the floor of the Cascadia Depression. A large water-column methane signal of unknown origin is present, but to date there is no direct evidence of a sea-floor hydrothermal system. However, the probable presence of intrusive bodies within the sedimentary sequence of the Cascadia Depression could give rise to sediment-hosted sulfide bodies such as those of the Guaymas Basin in the Gulf of California. The depressions at either end of the BTFZ (the Gorda and Blanco Depressions) are largely unexplored, but sulfide-veined greenstone breccias and hydrothermal sediments have been recovered from them. Oceanic transform fault zones such as the Blanco may also have hydrothermal systems associated with deep fracturing and high topographic relief.

EMBLEY, R.W., I.R. Jonasson, M.R. Perfit, J.M. Franklin, M.A. Tivey, A. Malahoff, M.F. Smith, and T.J.G. Francis. Submersible investigation of an extinct hydrothermal system on the Galapagos Ridge: Sulfide mounds, stockwork zone, and differentiated lavas. *Canadian Mineralogist 26*, 517-539 (1988).

Fifteen dives along the Galapagos Ridge in the region between 85°49'W and 85°55'W were made to examine the detailed relationships among tectonics, hydrothermal activity and lava compositions. Extensive tectonic activity and physical weathering have exposed the inner parts of large Cu-Zn sulfide mounds and the uppermost part of the underlying stockwork zone. The mineralization occurs at the top and southern base of a horst block, 40 to 80 m high, that separates the present Neovolcanic Zone to the north from an older rift valley to the south. The lavas in the Neovolcanic Zone are homogeneous MORB pillows; those on the horst block and within the southern valley are evolved MORB to andesite pillow and sheet flows. The alteration zone exposed beneath the sulfide mounds comprises a network of fracture-controlled pipe and sheet-like bodies of highly altered material which changes outward into relatively fresh but similarly closely fractured rocks. The hydrothermal upflow zone is extensively brecciated on a centimeter scale and encloses a stockwork of veinlets now filled largely by silica, clays and sulfides. The most highly altered rocks are strongly

depleted in Ca, Na, K and Mn, and are enriched in S, Fe, Cu and Zn relative to their fresh analogs. Si and Mg are variable, the latter showing local depletions and enrichments according to the proportion and distribution of chlorite. Depletions in ^{18}O with increasing $^{87}Sr/^{86}Sr$ suggest extensive seawater-rock interaction (W/R up to 100:1) at T up to 350°C. Deep-tow and ALVIN-based magnetic profiles have a relative magnetization low centered over the southern valley and the horst block that could reflect more extensive hydrothermal alteration zones associated with the older seafloor. The Galapagos stockwork is most analogous to the alteration zones associated with massive sulfide deposits in the ophiolites of Cyprus and Oman.

During two *Atlantis II/Alvin* cruises to the Juan de Fuca Ridge in 1984 active high temperature (140°-284°C) vents were sampled for black smoker particulates using the Grassle Pump. Individual mineral phases were identified using standard X-ray diffraction and petrographic procedures. In addition, elemental compositions and particle morphologies were determined by X-ray energy spectrometry and scanning electron microscope/X-ray energy spectrometry techniques. The vent particulates from the southern Juan de Fuca Ridge vent sites were highly enriched in S, Si, Fe, Zn, and Cu and were primarily composed of sphalerite, wurtzite, pyrite, pyrrhotite, barite, chalcopyrite, cubanite, hydrous iron oxides, and elemental sulfur. Two additional unidentified phases which were prevalent in the samples included an Fe-Si phase and a Ca-Si phase. The grain sizes of the individual particle phases ranged from <2 μm for the sphalerite and Fe oxide particles to >100 μm for the Fe-Si particles. Grain size and current meter data were used in a deposition model of individual phase dispersal. For many of the larger sulfide and sulfate particles, the model predicts dispersal to occur over length scales of only several hundreds of meters. The high-temperature black smokers from the more northerly Endeavour Segment vents were highly enriched in Fe, S, Ca, Cu, and Zn and were primarily composed of anhydrite, chalcopyrite, sphalerite, barite, sulfur, pyrite, and other less abundant metal sulfide minerals. The grain sizes of the individual particles ranged from <10 μm to slightly larger than 500 μm. The composition and size distributions of the mineral phases are highly suggestive of high-temperature mixing between vent fluids and seawater. A series of field and laboratory studies were conducted to determine the rates of dissolution of several sulfate and sulfide minerals. The dissolution rates ranged over more than three orders of magnitude, from 3.2×10^{-8} cm s^{-1} for anhydrite to 1.2×10^{-12} cm s^{-1} for chalcopyrite. The results indicate that for some minerals, particularly anhydrite and marcasite, total dissolution occurs within a few hours to a few weeks of their formation. For other more stable minerals, including pyrite, sphalerite and chalcopyrite, the time required for total dissolution is much longer. and consequently, individual crystals may be expected to persist in the sediments for considerable periods of time after deposition.

FEELY, R.A., A.J. PAULSON, H.C. CURL, JR., and D.A. TENNANT. The effect of the Duwamish River plume on horizontal versus vertical transport of dissolved and particulate trace metals in Elliott Bay. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 172-184 (1988).

No abstract.

Fleagle, R.G., N.A. BOND, and W.A. Nuss. Atmosphere-ocean interaction in mid-latitude storms. *Meteorology and Atmospheric Physics* 38:50-63 (1988).

Surface fluxes of heat, latent heat, and momentum, and entrainment fluxes and vertical motion at the top of the boundary layer have been calculated for limited regions of several mid-latitude ocean storms. Results have been combined to describe distributions of boundary layer processes which are characteristic of such storms. Surface heat fluxes have important effects in the region west of cold or occluded fronts and are relatively unimportant with a band of about 200 km width east of fronts. Entrainment in pre-frontal regions is driven largely by vertical shear at the top of the boundary layer, while in post-frontal regions is is driven largely by surface heat flux. Boundary layers are well defined in regions more than roughly 200 km east or west of fronts; but closer to fronts boundary layers are not well defined due to the combined effects of entrainment, condensation, and vertical motion associated with the distribution of surface stress.

Foldvik, A., K. AAGAARD, and T. Tørresen. On the velocity field of the East Greenland Current. *Deep-Sea Research* 35(8):1335-1354 (1988).

Year-long moored measurements from the East Greenland Current near 79°N show its mean southward transport above 700 m to be about 3 Sv and with no obvious seasonal variability. About one-half of this transport appears to be barotropic. There is a rich mesoscale structure in the records, much of which can be interpreted as trains of eddies and eddy-pairs with cross-stream length scales of order 10 km. The lower frequency perturbations typically extend to at least 400 m. Despite the abundance of eddies, their contribution to the heat flux is very small even in the vicinity of the polar front. Local baroclinic instability is therefore not a major source of eddies.

FOX, C.G., K.M. MURPHY, and R.W. EMBLEY. Automated display and statistical analysis of interpreted deep-sea bottom photographs. *Marine Geology* 78:199-216 (1988).

An automated system for interpreting and displaying deep-sea bottom photographs has been developed which allows rapid compilation and analysis of geological information. Initially, collected photographs are classified using a scheme similar to those applied to deep-sea volcanic and hydrothermal terrains by other workers. Towed-camera positions from a transponder navigation system are smoothed using a cubic spline technique to obtain a more accurate model of the tow-vehicle track. Line scan recorded data of the camera's height

above the seafloor and camera lens characteristics are used to calculate the field of view for each photograph. These data sources are integrated to produce a graphic output which combines the location, orientation, field of view, geological, and biological information for all photographs in a single color display. An illustration of the technique is presented for a photographic data set collected within the caldera of Axial Seamount (45°57'N, 130°03'W), a site of active high and low temperature hydrothermal venting on the central Juan de Fuca Ridge. Results confirm the existence and pinpoint the locations of several areas of known hydrothermal activity within the caldera. Quantitative analyses of the data base indicate statistical associations between various geological and hydrothermal parameters. In particular, rigorous statistical testing indicates that hydrothermal activity is associated with regions dominated by sheet flow lavas and fracturing.

FREITAG, H.P., and M.J. MCPHADEN. EPOCS moored temperature, current and wind measurements: 0°, 140°W; May-June, 1987. NOAA DR ERL PMEL-23 (PB88-219415), 31 pp. (1988).

No abstract.

Froelich, P.N., M.A. Arthur, W.C. Burnett, M. Deakin, V. Hensley, R. Jahnke, L. Kaul, K.-H. Kim, K. ROE, A. Soutar, and C. Vathakanon. Early diagenesis of organic matter in Peru continental margin sediments: phosphorite precipitation. *Marine Geology* 80:309-343 (1988).

Pore water chemistry (total dissolved CO_2, NH_4, NO_3, NO_2, PO_4, $Si(OH)_4$, Ca, Mg, Fe, Mn, SO_4, H_2S and F, and titration alkalinity), solid phase chemistry (C_{org}, P_{org}, C_{TOT}, N_{TOT}, P_{TOT}, F, Si_{OPAL} and S_H), and sediment characteristics (porosity, dry bulk density and formation factors) were determined on a centimeter-scale spacing in the upper 20-40 cm of sediments under intense upwelling areas on the Peru continental shelf. These data demonstrate that carbonate fluorapatite (CFA) is precipitating from pore waters in the upper few centimeters of a gelatinous mud with high organic carbon content (up to 20% C_{org}), very high porosity (>0.96 ml cm^{-3}) and very low dry bulk density (<0.1 g cm^{-3}). Dissolved phosphate concentrations at the sediment-water interface range from 20 to 100 µM, orders of magnitude higher than bottom-water concentrations, and much higher than predicted from regeneration of organic matter. The mechanism of this interfacial phosphate release is unclear, but is apparently uncoupled from carbon and nitrogen metabolism and thus may be linked either to dissolution of fish debris or to the presence of a microbial mat in surficial sediments. Fluoride is incorporated into CFA by diffusion from the overlying seawater, and carbonate ions are provided from pore-water alkalinity. Magnesium concentrations in this reaction zone are not significantly different from those of seawater, suggesting that magnesium depletion is not a necessary prerequisite for CFA precipitation. The environment of precipitation is interface-linked rather than driven by organic diagenesis of phosphorus deeper in the sediment. Most of the cores display a wide range of diagenetic characteristics below the immediate interfacial region, but almost all show the precipitation signature near the interface. This interface-linked early diagenetic pore-water environment for the precipitation of CFA explains many of the geochemical characteristics of phosphorites and provides a

"testable" model to compare the modern phosphogenic analog with ancient phosphorite deposits. Two of the cores display very high solid phase phosphorus and fluoride contents reflecting the presence of apparently modern pelletal apatites.

GONZALEZ, F.I., E.N. BERNARD, H.B. MILBURN, D. Castel, J. Thomas, and J.M. Hemsley. The Pacific Tsunami Observation Program (PacTOP). Proceedings of the International Tsunami Symposium, Vancouver, British Columbia, Canada, August 18-19, 1987, International Union of Geodesy of Geophysics, ERL Special Report (PB89-100895), 3-19 (1988).

PacTOP is a cooperative effort by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Army Corps of Engineers (USACE) to establish a monitoring network capable of acquiring high quality tsunami data in the deep ocean and at exposed coastal sites. The network is designed to monitor major portions of the seismically active Aleutian trench which possess high potential for tsunamigenic earthquakes, and is thus focused on tsunami events which would threaten Alaska, the U.S. west coast and Hawaii. This network is in its second year of development, and presently consists of five NOAA deep ocean bottom pressure recorder (BPR) stations, six primary USACE pressure gauges at shallow water coastal sites exposed to the open ocean, and three secondary USACE stations inside of coastal inlets. Station locations, instrument characteristics, and data collection procedures are described.

GONZALEZ, F.I., C. FOX, and E.N. BERNARD. Tsunami source definition through pre- and post-event seafloor mapping. Proceedings of the Third Biennial National Ocean Service International Hydrographic Conference, Baltimore, MD, April 12-15, 1988, 102-108 (1988).

Accurate specification of a tsunami source is a serious and long-standing research problem. Existing seafloor mapping technology could provide estimates of permanent seafloor displacements through pre- and post-event surveys taken before and after major oceanic earthquakes. It is probable that the next major tsunamigenic earthquake which threatens the United States will occur shoreward of the Aleutian trench near the Shumagin Islands, in a region known as the Shumagin Seismic Gap. We urge the expeditious mapping of this area to ensure that a pre-event survey is completed before the predicted earthquake.

GRAY, J. Scales of adjustment of offshore-directed winds along a mountainous coast. Fourth Conference on Meteorology and Oceanography of the Coastal Zone, Ahaheim, CA, Jan. 31-Feb. 5, 1988. American Meteorological Society, Boston, 12-17 (1988).

No abstract.

HARRISON, D.E. Monthly mean island surface winds in the central tropical Pacific and El Niño events. *Monthly Weather Review* 115(12):3133-3145 (1987).

The monthly mean surface wind changes during recent ENSO events, as observed from 11 islands in the tropical Pacific, are described. Two different composite ENSO wind fields are evaluated and compared. The month-to-month wind changes during each event are also discussed. The wind changes for each event between 1953 and 1980 except 1969 show several common features: (i) Westerly anomalies appear first west of the dateline and then at the dateline sometime in summer (0) to fall (0), then intensify over the following several months. The anomalies are confined to within ±3° of the equator during this stage. (ii) In either November (0), December (0), or January (+1) there is an abrupt southward shift of the narrow band of westerly anomalies, so that the maximum anomaly is then at ~5°S latitude at the dateline, and nearly normal conditions prevail north of the equator. (iii) Westerly anomalies are gone or greatly reduced one to two months after the southward shift. The event-to-event variations are considerable, particularly prior to July (0) and after February (+1), so that composites show much reduced anomaly amplitude and much smaller month-to-month anomaly changes than are typical of any given event. The large amplitude months of the composites show similarities with a composite by Rasmusson and Carpenter, but a number of significant differences are identified. These findings, and their relationship to existing simple ideas concerning tropical Pacific coupled ocean-atmosphere interactions, are discussed.

HARRISON, D.E. Ocean circulation model hindcasts of the 1982-83 El Niño. Japan-U.S. Workshop on the ENSO Phenomenon, T. Matsuno and M. Blackmon (eds.), Meteorological Research Report 88-1, Division of Meteorology, Geophysical Institute, University of Tokyo, March, 1988, 179-184 (1988).

No abstract.

HARRISON, D.E. Recent tropical Pacific surface wind variability studies. Japan-U.S. Workshop on the ENSO Phenomenon, T. Matsuno and M. Blackmon (eds.), Meteorological Research Report 88-1, Division of Meteorology, Geophysical Institute, University of Tokyo, March, 1988, 94-98 (1988).

No abstract.

HARRISON, D.E., and B.J. Giese. Remote westerly wind forcing of the eastern equatorial Pacific; some model results. *Geophysical Research Letters* 15(8):804-807 (1988).

An ocean circulation model is used to examine modes of eastern Pacific ocean response to an episode of surface westerly winds in the western Pacific. This episode resembles the May 1986 tropical cyclone pair event. The ocean changes resulting from this episode are isolated by subtracting the circulation that would otherwise have been present. First and second mode baroclinic Kelvin pulses have comparable surface eastward flow, and cause local warming when the surface temperature gradient is negative. The Kelvin pulses also introduce modulations of the eastern Pacific instability waves, which initially increase the mid-ocean warming

and then damp it out. South American coastal warming is substantial, but occurs many months after the wind event because it results primarily from the second baroclinic mode response. Recent analyses of the ocean response to the cyclone event have concentrated on the first mode Kelvin pulse response; this work indicates that only a very incomplete view of the response is possible from this perspective.

HARRISON, D.E., W.S. Kessler, and B.S. Giese. Model-data comparisons for the 1982-83 El Niño: The XBT tracks. NOAA TM ERL PMEL-79 (PB88-221668), 61 pp. (1988).

Five different analyses of 1982-83 monthly average surface wind stress fields have been used to force an ocean general circulation model of the tropical Pacific, in a series of El Niño hindcast experiments like that reported by Philander and Seigel (1985). The results of these hindcasts are compared here with the variability of upper ocean dynamic height, sea surface temperature and subsurface temperature as observed from XBT data obtained along the three main ship of opportunity tracks. During 1982-83 there were prominent departures from climatology in the surface wind stress field. However, there are so few observations of surface wind available that efforts to produce fields of wind stress must fill in considerable gaps in data coverage, with the result that the various tropical surface analyses tend to differ considerably; the differences between analyses, along the ship tracks, are described. Generally the operational analyses produced by the meteorological centers (National Meteorological Center (NMC), European Center for Medium-range Weather Forecasting (ECMWF), and Fleet Numerical Ocean Central (FNOC)) had weaker surface stress and weaker spatial gradients than the special research products (Florida State University (FSU) and Sadler (SADLER)). The ocean underwent several major changes during this period according to the XBT data; these changes are summarized. The model hindcasts are examined to determine the extent to which the observed major ocean changes were reproduced. Within the equatorial waveguide, dynamic height changes are hindcast with quantitative skill using each wind stress field; the best hindcasts differ from the observations by only a few dyn cm more than the estimated uncertainty in the observations. The large waveguide dynamic height hindcast skill found here indicates that the major elements of the 1982-83 El Niño are contained in the 1982-83 surface wind stress field, rather than in any particular aspect of the state of the ocean during late 1981. Sea surface temperature changes are generally hindcast with some qualitative skill; the correlation between hindcast and observed SST is usually significantly positive, but the RMS difference between any hindcast and the observations is generally greater than the RMS signal in the observations. Subsurface temperature variability is hindcast with differing levels of skill, depending upon stress field, region and depth. The vertical temperature gradients and mixed layer temperatures, as well as the depth of the thermocline, undergo substantial changes (especially in the eastern Pacific); primitive equation physics appear necessary to model these observations. Outside the waveguide, hindcast skill is generally much reduced; although qualitatively correct behavior is often hindcast, amplitudes can be seriously in error. The most striking inconsistency found involves the NMC hindcast in the region of the North Equatorial Counter Current. The special research products generally give more accurate hindcasts of dynamic height, but the operational fields often produce better SST hindcasts. A clear deficiency of the operational fields is the character of their wind stress curl fields, compared either with climatology or the special research

analyses; because Ekman pumping is a major factor in thermocline adjustment outside the waveguide, wind stress curl must be correctly represented if adequate hindcasts are to be obtained. Although improved parameterization of upper ocean mixing, and better knowledge of the surface heat flux appear needed to improve SST hindcast skill, these results establish that a most serious need for improved hindcast performance is better knowledge of the surface wind stress field.

HAYES, S.P. Benthic currents in the deep ocean. In *The Manganese Nodule Belt of the Pacific Ocean*, P. Halbach, G. Friedrich, and U. von Stackelberg (eds.). Ferdinand Enke Verlag Stuttgart, 90-102 (1988).

No abstract.

HAYES, S.P. Wind coherence estimates along 165°E. Proceedings U.S. TOGA Western Pacific Air-Sea Interaction Workshop, September 16-18, 1987, R. Lukas and P. Webster (eds.), UCAR-USTOGA 8, 155-161 (1988).

No abstract.

Jacobson, R.S., L.D. Bibee, R.W. EMBLEY, and S.R. HAMMOND. A microseismicity survey of Axial Seamount, Juan de Fuca Ridge. *Bulletin of the Seismological Society of America* 77(1):160-172 (1988).

An array of ocean bottom seismometers and hydrophones were deployed within the caldera of Axial Seamount, located at the intersection of the Cobb-Eickelberg Seamount Chain and the Juan de Fuca Ridge. Recent manned submersible dives have discovered the presence of two distinct hydrothermal vent fields. The objective of the microseismicity survey was to determine baseline information necessary for designing an optimal experiment to monitor seismicity associated with submarine volcanic and hydrothermal systems. With an instrument deployment period of eight days, over 1500 events were recorded and examined. Most events occurred within three periods of swarm activity. The location of the swarm events is believed to be within the low temperature vent field in the northwest portion of Axial's caldera. These impulsive, high-frequency events are interpreted to be tectonic in origin. No harmonic tremor-like events were observed on any of the instruments, indicating a lack of magmatic movement. Only nine local events were recorded on more than one instrument, and none of these could be located unambiguously. Monochromatic 20-Hz signals were also recorded and are interpreted to originate from whales observed in the immediate vicinity.

JOHNSON, J.E., and J.E. Lovelock. Electron capture sulfur detector: reduced sulfur species detection at the femtomole level. *Analytical Chemistry* 60:812-816 (1988).

We have developed a new technique to detect reduced sulfur compounds by fluorination with

F_2 (at 200 ppm) on a heated Ag catalyst after GC separation. The excess F_2 is removed by conversion to HF by reaction with H_2 on a heated Pd catalyst. The fluorination product, presumably SF_6, is then detected in an electron capture detector (ECD). The Pd catalyst also destroys the response from halocarbons making the system sulfur specific. This ECD sulfur detector has a calculated minimum detectable level (MDL) for H_2S, OCS, CH_3SH, DMS, and CS_2 of less than 2 fmol/s for each compound, 2 orders of magnitude lower than the best FPD systems. The ratio of the detected molar response of each of these sulfur compounds to the molar response of SF_6 ranges from 2% to 20% and increases with increasing AgF_2 temperature.

LACKMANN, G.M. Evaluation of the Rossby Radius for offshore-directed flow near a mountainous coast. Preprints, Fourth Conference on Meteorology and Oceanography of the Coastal Zone, Anaheim, CA, Jan. 31-Feb. 5, 1988. American Meteorological Society, Boston, 1-5 (1988).

No abstract.

LAVELLE, J.W. A laterally averaged model of currents in Admiralty Inlet and the main basin of Puget Sound. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 89-92 (1988).

No abstract.

LAVELLE, J.W., and H.O. MOFJELD. Closure to "Do critical stresses for incipient motion and erosion really exist?" *Journal of Hydraulic Engineering* 114:962-963 (1988).

No abstract.

LAVELLE, J.W., E. Ozturgut, E.T. BAKER, D.A. TENNANT, and S.L. WALKER. Settling speeds of sewage sludge in seawater. *Environmental Science and Technology* 22(10):1201-1207 (1988).

Laboratory analyses of sludges from four treatment plants were performed to determine solid content, size distributions, and settling spectra of sludge particulates in sewawater. The settling experiments were conducted after partitioning samples by sieving into coarse and fine particulate fractions. For the fine fraction, experiments proceeded after controlled mixing of samples with filtered seawater to particulate concentrations low enough (~10 mg/L) that flocculation was limited during subsequent measurement periods. Results show that 14.6-47.3% of the sludge particulates by weight had diameters greater than 63 μm, with at least 5% exceeding 250 μm. Median settling velocities of this fraction ranged from 6×10^{-2} to 3×10^{-1} cm/s. The bulk of the particulates were smaller in diameter, and these flocculated in seawater. Resulting aggregates had median settling velocities by volume

ranging from 7×10^{-4} to 3×10^{-3} cm/s, with less than 10% of the particles settling more slowly than 10^{-4} cm/s.

LYNCH, J.M., L.J. MANGUM, and S.P. HAYES. CTD/O_2 measurements during 1986 as part of the Equatorial Pacific Ocean Climate Studies (EPOCS). NOAA DR ERL PMEL-24 (PB89-102859), 261 pp. (1988).

During 1986, CTD data were collected in the eastern equatorial Pacific as part of the Equatorial Pacific Ocean Climate Studies (EPOCS) program, which began its field program in 1979. Summaries of CTD data from three cruises in 1986 are presented. Station locations, meteorological conditions and profiles of temperature, salinity, sigma-T, and oxygen are shown for each cast. Additionally, T-S diagrams and section-plots along 110°W, 140°W, 15°S and the equator are presented.

MACKLIN, S.A. Fisheries-Oceanography Coordinated Investigations (FOCI) surface meteorological observations at Cherni Island and Ugaiushak Island--Fiscal Year 1986. NOAA DR ERL PMEL-21 (PB88-179270), 15 pp. (1988).

No abstract.

MACKLIN, S.A. Structure of a mountain-gap wind blowing over a coastal inlet. Preprints, Fourth Conference on Meteorology and Oceanography of the Coastal Zone, Anaheim, CA, Jan. 31-Feb. 5, 1988. American Meteorological Society, Boston, 6-11 (1988).

No abstract.

MACKLIN, S.A., G.M. LACKMANN, and J. GRAY. Offshore-directed winds in the vicinity of Prince William Sound, Alaska. Monthly Weather Review 116(6):1289-1301 (1988).

The thermal contrast between cold air over continental Alaska and relatively warm marine air over the Gulf of Alaska causes frequent, low-level, offshore-directed winds over the south-central Alaskan coast during the cold season. Coastal mountains affect these winds by inhibiting low-level mixing of continental and marine air masses near the coast, by providing channels that focus and accelerate drainage winds, and by exciting mountain-lee waves. Offshore-directed winds were observed twice with a research aircraft. The strongest winds were measured at the mouth of the Copper River and over and downwind of Resurrection Bay. The synoptic weather pattern and its orientation to local topographic features influenced wind magnitude. With the pressure gradient perpendicular to the coast, offshore-directed flow was light except at the Copper River and Resurrection Bay drainages. When the pressure gradient was aligned with the shore, regional surface winds were stronger and more uniform, although the Copper River and Resurrection Bay drainages were still discernible. Evaluation of local force balances showed the largest ageostrophy at coastal locations

downwind of bays and river valleys. Seaward from the coast, ageostrophic accelerations and cross-isobaric wind components were smaller, indicating a transition toward geotriptic equilibrium. This spatial adjustment pattern is consistent with the hypothesis that equilibrium is achieved within a distance similar to the regional Rossby radius of deformation.

MCPHADEN, M.J., A.J. Busalacchi, and J. Picaut. Observations and wind-forced model simulations of the mean seasonal cycle in tropical Pacific sea surface topography. *Journal of Geophysical Research* 93(C7):8131-8146 (1988).

We examine simulations of the mean seasonal cycle in the tropical Pacific using a multiple vertical mode linear numerical model forced with three different surface wind stress products averaged over the period 1979-1981. The model is run to equilibrium for each of four vertical modes, and results are summed. Simulated mean seasonal cycles in dynamic height and sea level are then compared with observed variations based on expendable bathythermograph and island tide gauge data averaged over the same 1979-1981 period. All simulations show characteristic features of the mean meridional ridge-trough structure in surface topography. However, north and south equatorial ridges at 20°N and 20°S are much higher than those observed, only weak equatorial ridges are generated near 4°N, and none of the simulations exhibits a significant equatorial trough. These discrepancies are due principally to limitations in model physics and in the wind forcing. Observed and modeled mean seasonal variations in surface height are of the order of a few centimeters. Coherence estimates of 0.5-0.7 are found between the model simulations and the observations for the 1 cycle per year harmonic, which dominates the seasonal cycle over most of the tropical Pacific. This suggests that about 25-50% of the variance in the observed annual surface height is accounted for by the linear model, given current estimates of the surface wind field. Harmonics higher than the annual are less well modeled because of their weaker signal levels. Regional patterns are observed in coherence levels between modeled and observed variability; i.e., longitudinally, the eastern Pacific is most poorly modeled, while latitudinally, the equatorial band (5°N to 5°S) is best modeled. However, no wind stress product is clearly superior to the others for simulating the mean seasonal cycle. Thus uncertainty in the surface stress field remains a fundamental obstacle to more accurate modeling of the variability in tropical Pacific sea surface topography.

MCPHADEN, M.J., A.J. Busalacchi, J. Picaut, and G. Raymond. A model study of potential sampling errors due to data scatter around expendable bathythermograph transects in the tropical Pacific. *Journal of Geophysical Research* 93(C7):8119-8130 (1988).

We describe a series of sampling sensitivity experiments to examine potential errors due to data scatter around expendable bathythermograph (XBT) transects in the tropical Pacific. We use a linear, multiple vertical mode model forced with three different monthly mean wind stress sets for the period 1979-1983. The model is sampled along approximately straight lines of grid points corresponding to the mean positions of XBT tracks in the eastern, central, and western Pacific and then sampled again at the dates and locations of actual XBT casts for 1979-1983. Model dynamic heights are calculated with a resolution of 1° of latitude and 1

month, then processed to a monthly mean seasonal cycle and anomalies associated with the 1982-1983 El Niño. When results are compared for the two methods of sampling, the model indicates that data scattered zonally around XBT transects in general can lead to about 2 dyn cm error in dynamic height (equivalent to a 10-m error in model pycnocline displacement) in composite sections of XBT data. This magnitude of error generally does not obscure anomalies associated with the 1982-1983 El Niño or the annual and semiannual harmonics of the mean seasonal cycle in the model, though frequencies higher than the semiannual can be adversely affected. Errors larger than 2 dyn cm occur in regions where XBT sample spacing in the zonal direction is insufficient to resolve Rossby wave variations in the model (for example, from 16°N to 20°N in the central Pacific and from 8°S to 20°S in the eastern Pacific). These conclusions are insensitive to the choice of monthly mean wind stress used to force the model.

MCPHADEN, M.J., H.P. FREITAG, S.P. HAYES, and B.A. TAFT. The response of the equatorial Pacific Ocean to a westerly wind burst in May 1986. *Journal of Geophysical Research* 93(C9):10589-10603 (1988).

Western Pacific westerly wind bursts of 1- to 3-week duration are potentially important in triggering and sustaining El Niño-Southern Oscillation events. One such burst of 10-day duration and maximum speeds of greater than 10 m s^{-1} occurred in May 1986 west of the date line. The response to this westerly wind burst is documented from equatorial current meter moorings, thermstor chain moorings, and sea level and hydrographic data. At 0°, 165°E in the western Pacific the thermocline was depressed by 25 m, sea surface temperature dropped by 0.3°-0.4°C, and sea level rose by 10-15 cm a few days after the maximum in westerly wind speed. Likewise, the South Equatorial Current rapidly accelerated eastward and attained speeds in excess of 100 cm s^{-1}. Vertical shear in an approximately 100 m deep surface layer reversed within a few days of the winds, consistent with a simple model of equatorial mixed layer dynamics in which vertical eddy viscosities are inferred to be O(100 cm2 s^{-1}). A sharp Kelvin wavelike pulse in sea level propagated out of the directly forced region into the central and eastern Pacific. The pulse took 45 days to travel from Tarawa (1°N, 173°E) to La Libertad (2°S, 81°W) on the South American coast, at an average phase speed of about 300 cm s^{-1}. This is of the same order of magnitude as, but significantly higher than, the phase speed of a first baroclinic mode Kelvin wave and is probably the result of Doppler shifting by the Equatorial Undercurrent. A rise in sea surface temperature of about 1°C in 2 days occurred at 0°N, 110°W with the passage of the pulse. However, coincidental meridional advection of a sharp sea surface temperature front, rather than zonal advection of downwelling associated with the pulse, appears to be responsible for this warming. The relevance of this wind-forced pulse to the subsequent evolution of the 1986-1987 El Niño-Southern Oscillation event is discussed in the light of these observations.

Mobley, C.D. A numerical model for the computation of radiance distributions in natural waters with wind-roughened surfaces, Part II: Users' guide and code listing. NOAA TM ERL PMEL-81 (PB88-246871), 170 pp. (1988).

This report is a users' guide for and listing of the FORTRAN V computer code that implements a numerical procedure for computing radiance distributions in natural waters. The mathematical details of the numerical radiance model are described in a companion report (A numerical model for the computation of radiance distributions in natural waters with wind-roughened surfaces, by Curtis D. Mobley and Rudolph W. Preisendorfer, NOAA Technical Memorandum ERL PMEL-75). The present report describes how to run the computer model and therefore addresses questions such as which routines perform which calculations, what input is required by the various programs, and what is the file structure of the overall program.

Mobley, C.D., and R.W. PREISENDORFER. A numerical model for the computation of radiance distributions in natural waters with wind-roughened surfaces. NOAA TM ERL PMEL-75 (PB88-192703), 195 pp. (1988).

This report is a repository of the details of derivation of a numerical procedure to determine the unpolarized radiance distribution as a function of depth, direction, and wavelength, in a natural hydrosol such as a lake or sea. The input to the model consists of (i) the incidence radiance distribution at the air-water surface, (ii) the state of randomness of the air-water surface as a function of wind speed, (iii) the volume scattering and volume attenuation function of the medium as a function of depth and wavelength, and (iv) the type of bottom boundary. The fundamental mathematical operation in the development of the numerical model is the discretization over direction space of the continuous radiative transfer equation. The directionally discretized radiances, called quad-averaged radiances, are the averages over a finite set of solid angles of the directionally continuous radiance. The quad-averaged equations are azimuthally decomposed using standard Fourier analysis to obtain equations for the quad-averaged radiance amplitudes. These amplitude equations are then developed in terms of reflectance and transmittance functions. The reflectances and transmittances are continuous functions of depth and are governed by a set of Riccati equations which is easily integrated. The depth-dependent, quad-averaged radiances are assembled from the solution reflectances and transmittances of the water body, in combination with the boundary conditions. The model has an expandable library of derived quantities that are of use in various applications of optics to natural waters, such as marine biological studies, underwater visual search tasks, remote sensing, and climatology.

MOFJELD, H.O. Review of "Tides, Surges and Mean Sea-Level, A Handbook for Engineers and Scientists," by D.T. Pugh. *Eos, Transactions of the American Geophysical Union* 69(37):850 (1988).

No abstract.

MOFJELD, H.O. Seasonal and interannual variations of tidal mixing and excursions in Admiralty Inlet. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 99-102 (1988).

No abstract.

MOFJELD, H.O. and J.W. LAVELLE. Formulas for velocity, sediment concentration and suspended sediment flux for steady uni-directional pressure-driven flow. NOAA TM ERL PMEL-83 (PB89-109995), 26 pp. (1988).

A level 2 turbulence closure model for steady pressure-driven currents and suspended sediment concentrations in an unstratified channel leads to analytic formulas for the velocity and the concentration of each settling constituent. The level 2 model uses a parabolic form for the mixing length that increases linearly upward near the bottom and is a maximum at the surface. The model assumes a balance between local turbulence production and dissipation, and the sediment concentrations are assumed to be dilute. The level 2 velocity is found to follow closely the log velocity profile, being only $\sim 0.5u_*$ less than the log-profile at the surface, where u_* is the friction velocity (square root of the kinematic bottom stress). The level 2 concentration matches closely a modified form of the Rouse formula in which the actual depth H is replaced by $H' = 1.07\,H$. The model results provide a theoretical basis for the use of the log velocity and Rouse concentration profiles over the water column based on turbulence closure theory. The vertically integrated flux of suspended sediment (suspended load transport) per unit width computed numerically from the level 2 model are approximated well by the flux derived from the pure log velocity and unmodified ($H' = H$) Rouse concentration profiles. When normalized by the ratio of erosion rate to the settling velocity w_s, explicit formulas for the log-Rouse flux are functions of the two parameters $\beta = w_s/\kappa u_*$ and z_0/H (κ being the von Kármán constant, z_0 the bottom roughness and H the water depth) and is most sensitive to β; it is proportional to β^{-1} in the slow settling regime $\beta < 0.1$ and decreasing rapidly as $\beta^{-1}(\beta-1)^{-2}$ in the fast settling regime $\beta > 2$. The flux is a strong function of the bottom stress through the erosion rate which dominates the stress dependence in the slow settling regime.

J.N. Moum, D.R. Caldwell, and P.J. STABENO. Mixing and intrusions in a rotating cold-core feature off Cape Blanco, Oregon. *Journal of Physical Oceanography* 18(6):823-833 (1988).

During August 1986, a large cold anomaly was observed in satellite and in situ measurements near Cape Blanco at 42°N, 126°30'W off the Pacific Coast. Detailed vertical profiles of temperature, conductivity, turbulent dissipation, and horizontal currents showed 1) surface water temperature changes as large as 2 degrees in 1 kilometer (but smaller gradients at depth); 2) a structure in the mean currents resembling that of either a cyclonic eddy or a current meander; 3) a current field in geostrophic balance on scales of 10 km and greater; 4) a region of intrusions on the northern side of the eddy; 5) a concentration of turbulence (as indicated by the kinetic-energy dissipation rate) on the edges of the eddy and in the region of intrusions, the core of the eddy being turbulence-free; and 6) a substantial change in the surface structure in 24 hours.

Muench, R.D., J.D. SCHUMACHER, and S.A. SALO. Winter currents and hydrographic conditions on the northern central Bering Sea shelf. *Journal of Geophysical Research* 93(C1):516-526 (1988).

Current observations obtained from the northern Bering shelf region in winter 1984-1985 indicate that midwinter circulation patterns differed from those during the rest of the year. Annual mean circulation in this region is dominated by vigorous northward currents (from 10 cm/s in Shpanberg Strait to more than 50 cm/s in Bering Strait). These northward currents are accompanied by a weak northwestward coastal flow south of St. Lawrence Island. In February-April 1985, however, flow was weakly (0-5 cm/s) southward through Shpanberg Strait and southeastward south of St. Lawrence Island while remaining northward through Anadyr and Bering straits. Comparison with current data obtained from previous years suggests that midwinter reversal of flow in Shpanberg Strait is a recurrent winter feature. It generally occurs at about the same time that the winter ice cover undergoes its major advance, and it is associated with strong northerly winds. Northward flow through Anadyr Strait persists, conversely, through the winter and is the northward extension of a western intensified northward flow over the Bering Shelf. Its source is Bering Sea water farther south, rather than water from the northern central shelf. The resultant "trapping" of shelf water on the northern central shelf, coupled with intensive regional ice formation during the same period as the flow reversal, led in 1985 to significant (about 1.5‰) brine enrichment. This salinity increase agrees qualitatively with historical data, which suggest that the northern central Bering shelf is the site both of sluggish winter circulation and of elevated salinities due to brine enrichment from ice formation.

MURPHY, P.P., T.S. BATES, H.C. CURL, JR., R.A. FEELY, and R.S. BURGER. Retention of organic pollutants in Puget Sound. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 195-199 (1988).

Hydrocarbon concentrations were measured on suspended particulates and on surficial marine sediments in the urban fjord-like estuary of Puget Sound, Washington. These data were combined with sediment deposition rates, suspended particulate concentrations and circulation data to assess hydrocarbon distributions and fates. Evaluation of major sinks for petroleum hydrocarbons (UCM) and polycyclic aromatic hydrocarbons (PAH) in the urban estuary indicates that >93% of the hydrocarbons which are associated with suspended particulates in the main basin of Puget Sound are deposited in the estuarine sediments. Approximately 63% of the PAH and 100% of the UCM associated with particles in the main basin settle directly to the sediments. The remainder is carried to the main basin sediments via horizontal transport from other areas. Trends in PAH ratios are used to identify major sources of PAH. Estimated sources of PAH are balanced by the estimated sinks.

OVERLAND, J.E. A model of the atmospheric boundary layer over sea ice during winter. Preprints, Second Conference on Polar Meteorology and Oceanography, March 29-31, 1988, Madison, WI, American Meteorological Society, Boston, 69-72 (1988).

No abstract.

OVERLAND, J.E. Icebergs. The World Book Encyclopedia, Chicago, IL, Vol. 10, 17-18 (1988).

No abstract.

PAULSON, A.J., R.A. FEELY, H.C. CURL, JR., E.A. Crecelius, and T. GEISELMAN. The impact of scavenging on trace metal budgets in Puget Sound. *Geochimica et Cosmochimica Acta* 52:1765-1779 (1988).

The distributions of dissolved and particulate Mn, Pb, Cu and Zn in Puget Sound, its tributaries, and its sediments were determined to illustrate the impact of scavenging reactions on trace metal budgets of a large fjordlike estuary. About 75% of the dissolved Pb discharged into the main basin of Puget Sound was scavenged from the dissolved phase. The high particulate Pb concentrations in regions of high particulate Mn concentrations and the significant correlations between Pb and Mn concentrations on suspended particles demonstrate the importance of hydrous manganese oxide phases in scavenging dissolved Pb. Since particles are effectively retained within the main basin, scavenging results in the sedimentation of about 70% of the total Pb added to the main basin. Only isolated instances of scavenging of dissolved Cu and Zn were observed and the discharge rates of dissolved Cu and Zn from known sources were equal to their rates of advective removal within the errors of the budget. The remineralization of organically-bound particulate Cu is partly responsible for its quasi-conservative behavior within the main basin of Puget Sound. The fates of Cu and Zn are controlled mainly by physical processes such as advection and settling of particles. Advection removes about 60% of the total Cu and Zn added to the main basin while 40% is deposited in the sediments of Puget Sound.

PAULSON, A.J., R.A. FEELY, H.C. CURL, JR., E.A. Crecelius, and G.P. Romberg. Contrasting sources and fates of Pb, Cu, Zn and Mn in the main basin of Puget Sound. First Annual Meeting on Puget Sound Research, Seattle, WA, March 18-19, 1988, Puget Sound Water Quality Authority, 185-194 (1988).

No abstract.

PAULSON, A.J., R.A. FEELY, H.C. CURL, JR., E.A. Crecelius, and G.P. Romberg. Sources and sinks of Pb, Cu, Zn and Mn in the main basin of Puget Sound. NOAA TM ERL PMEL-77 (PB88-219464), 26 pp. (1988).

Municipal, industrial and atmospheric sources contributed 66% of the total Pb added to the main basin of Puget Sound. Advective inputs were the major sources of total Cu and Zn (~40%) while riverine and erosional sources contributed about 30%. The discharge of the particle-bound trace metals from rivers minimized the impacts of particulate anthropogenic sources, which constituted 50%, 23% and 18% of the total particulate Pb, Cu and Zn inputs, respectively. While advective transport was the major source of dissolved Cu and Zn (~60% of all dissolved inputs), industrial, municipal and atmospheric inputs contributed 85%, 30% and 38% of the dissolved Pb, Cu and Zn inputs, respectively. Diffusion of dissolved Mn was the major source of Mn to the main basin. About 75% of the dissolved Pb discharged into the main basin of Puget Sound was lost from the dissolved phase and was balanced by a similar gain in the particulate phase. Because of the effective retention of particles within the main basin, extensive scavenging resulted in about 70% of the total Pb added to the main basin being retained in the underlying sediments. The sources of dissolved and particulate Cu and Zn were comparable with the sinks within the errors of the analyses indicating their quasi-conservative nature. Advection removed about 60% of the total Cu and Zn added to the main basin while 40% was deposited in the sediments of Puget Sound. The rapid oxidative precipitation allowed only 10% of the dissolved Mn added to the main basin to leave the main basin in the dissolved form.

PEASE, C.H. Meridional heat transport by the ice and ocean in the western arctic. Preprints, Second Conference on Polar Meteorology and Oceanography, Madison, WN, March 29-31, 1988. American Meteorological Society, Boston, 16-19 (1988).

No abstract.

PREISENDORFER, R.W. Eigenmatrix representations of radiance distributions in layered natural waters with wind-roughened surfaces. NOAA TM ERL PMEL-76 (PB88-188701), 93 pp. (1988).

This report develops analytic, closed-form solutions for *radiance* distributions in natural waters such as lakes and seas. The solutions are valid in layered water bodies for which each layer has inherent optical properties (absorption and scattering functions) which are independent of depth within that layer. The water body is assumed free of internal light sources. The effects of a wind-blown air-sea surface are included. This work extends to the radiance level certain results which were previously known to hold for irradiances. The eigenmatrix formalism developed here is convenient for numerical computation of radiance distributions, given the inherent optical properties of the water and the desired boundary conditions at the water surface and bottom (the direct problem). Moreover, the formalism suggests an algorithm for solving the inverse problem: the determination of the inherent optical properties from measurements of the radiance distribution within a water body.

PREISENDORFER, R.W. Principal Component Analysis in Meteorology and Oceanography. C.D. Mobley (ed.), Elsevier Science Publishers, Amsterdam, 425 pp. (1988).

No abstract.

PREISENDORFER, R.W., and C.D. Mobley. Theory of fluorescent irradiance fields in natural waters. *Journal of Geophysical Research* 93(D9):10831-10855 (1988).

The theory of heterochromatic irradiance fields is developed from the fundamental principles of radiative transfer. The irradiance field in natural waters that have fluorescing stratified layers of chlorophyll and other organic material is determined. This is the direct solution of the irradiance field and assumes knowledge of the depth distribution of the inherent optical properties, in particular the spectral absorption and scattering functions. Conversely, these optical properties are determined from in situ irradiance measurements by inverting the direct solution for the irradiance field. This is the inverse solution of the irradiance field. These direct and inverse solutions provide the mathematical framework for optical assays of fluorescing matter in lakes and seas, using measurements of the irradiance field within such media. In particular, the concentrations of the various fluorescing substances within the water are determined from in situ spectral irradiance measurements.

PREISENDORFER, R.W., C.D. Mobley, and T.P. Barnett. The principal discriminant method of prediction: theory and evaluation. *Journal of Geophysical Research* 93(D9):10815-10830 (1988).

The Principal Discriminant Method (PDM) of prediction employs a novel combination of principal component analysis and statistical discriminant analysis. Discriminant analysis is based on the construction of discrete category subsets of predictor values in a multidimensional predictor space. A category subset contains those predictor values which give rise to a predictand (or observation) in that particular category. A new predictor value is then assigned to a particular category (i.e., a forecast is made) through the use of probability distribution functions which have been fitted to the category subsets. The PDM uses principal component analysis to define the multidimensional probability distribution functions associated with the category subsets. Because of its underlying discriminant nature the PDM is also applicable to problems in data classification. The PDM is applied to prediction problems using both artificial and actual data sets. When applied to artificial data the PDM shows forecast skills which are comparable to those of standard forecast techniques, such as linear regression and classical discriminant analysis. When applied to actual data in a forecast of the 1982-1983 El Niño, the PDM performed poorly. However, in forecasting winter air temperatures over North America, the PDM proved superior to other forecast techniques, after suitably filtering or smoothing the raw data in order to improve the signal-to-noise ratio. It is expected that the PDM will show its greatest advantage over other forecast techniques when the relation between predictors and predictand is nonlinear.

Quinn, P.K., R.J. Charlson, and T.S. BATES. Simultaneous observations of ammonia in the atmosphere and ocean. *Nature* 335:336-338 (1988).

Ammonia, being the dominant base other than sea salt in the remote marine troposphere, plays an important role in the acid-base chemistry of the atmosphere. An understanding of the cycling of ammonia through the marine environment has, until now, been hampered by the lack of concurrent measurements of key acidic and basic atmospheric and seawater species. Reported here are the result of simultaneous concentration measurements of these species during May 1987 in the coastal north-east Pacific Ocean environment. Gas (g) and particulate (p) phase data suggest that low concentrations of NH_3 (g) in the marine atmosphere lead to partly neutralized H_2SO_4 in aerosol particles and in rainwater. Gas-phase concentrations combined with seawater concentration measurements indicate that for the region and time period studied the ocean was a local source of atmospheric ammonia. These data, combined in a simple box model, suggest a marine boundary layer residence time of 3.6 h and 22 h for NH_3 (g) and NH_4^+ (p), respectively.

REED, R.K., J.D. SCHUMACHER, and A.T. ROACH. Geostrophic flow in the central Bering Sea, fall 1986 and summer 1987. NOAA TR ERL 433-PMEL 38 (PB88-174354), 13 pp. (1988).

Data from a synoptic CTD survey over a large region in the central Bering Sea in fall 1986 are used to derive the major features of circulation. Geopotential topographies reveal the following flows: (1) a well-developed eastward flow that subsequently turned toward the northwest; (2) a cyclonic gyre north of Amukta Pass; and (3) a weak flow, with some local intensifications, paralleling the continental slope. Volume transports, relative to 1000 db, in these branches (in the order above) were approximately (1) 4×10^6 s^3 s^{-1}; (2) 2×10^6 s^3 s^{-1}; and (3) 1×10^6 generally, but -4×10^6 s^3 s^{-1} in two locations. Also, a northward inflow through Amukta Pass was inferred from subsurface temperature. Data from a cruise in summer 1987 reveal a relatively strong northward flow through Amchitka Pass but the absence of inflow in Amukta Pass. Previous climatological and synoptic data sets have shown numerous eddylike features that appear to be transient. Comparison of results from various circulation patterns suggests that the eastward flow that turns toward the northwest frequently occurs.

SALO, S., R.D. Muench, and J.D. SCHUMACHER. Oceanographic conditions on the northern Bering Sea shelf: 1984-1985. NOAA TM ERL PMEL-80 (PB88-231758), 55 pp. (1988)

No abstract.

SOREIDE, N.N., and S.P. HAYES. A system for management, display and analysis of oceanographic time series and hydrographic data. Preprints, Fourth International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology, Anaheim, CA, Jan. 31-Feb. 5, 1988. American Meteorological Society, Boston, J20-J22 (1988).

No abstract.

VAN HEESWIJK, M., and C.G. FOX. Iterative method and FORTRAN code for nonlinear curve fitting. *Computers and Geosciences* 14(4):489-503 (1988).

A FORTRAN subroutine is presented which allows the iterative, least-squares fitting of discrete, observational data by a nonlinear function. The function may have any number of parameters, provided that partial derivatives with respect to each of the parameters can be calculated. A brief discussion of the mathematical theory is presented, instructions for use of the subroutine are provided, and examples and performance tests of the algorithm are discussed.

WALKER, S.L., and E.T. BAKER. Particle-size distributions within hydrothermal plumes over the Juan de Fuca Ridge. *Marine Geology* 78:217-226 (1988).

The particle-size distributions of suspended particles in neutrally buoyant hydrothermal plumes from two vent sites on the Juan de Fuca Ridge were measured with a Coulter counter. Hydrothermal particle populations were characterized by high volume concentrations of particles with diameters of <2 μm. Particle populations dominated by larger particles were rare and observed only very near active vent sources because of rapid settling and dilution. Particle-size distributions from particle plumes of hydrothermal origin can be readily distinguished from those of benthic nepheloid layers by the fine-particle tail, which is expressed on a cumulative number distribution by a slope much steeper than the oceanic norm of ~3. The predominance of particles with diameters <2 μm within neutrally buoyant hydrothermal plumes demonstrates that the bulk of hydrothermal precipitates are capable of being dispersed over wide areas.

WALTER, B.A. The role of the St. Lawrence Polynya in the downwind modification of the planetary boundary layer over the Bering Sea ice pack. Preprints, Second Conference on Polar Meteorology and Oceanography, Madison, WN, March 29-31, 1988. American Meteorological Society, Boston, 61-64 (1988).

No abstract.

WISEGARVER, D.P. and R.H. GAMMON. A new transient tracer: measured vertical distribution of CCl_2FCClF_2 (F-113) in the north Pacific subarctic gyre. *Geophysical Research Letters* 15(2):188-191 (1988).

The first quantitative marine measurements of trichlorotrifluoroethane (F-113) were made in the North Pacific subarctic gyre in July of 1986, using a modification of the analytical procedure developed for the transient tracers F-11 and F-12 (Gammon *et al.*, 1982; Wisegarver and Cline, 1985). The measured mixed layer concentration was 0.29 ± 0.2 pM/L; the corresponding atmospheric mixing ratio was 35 ± 1 pptv (Rasmussen scale). Below a subsurface maximum both F-11 and F-113 were found to fall off exponentially with increasing depth, F-113 reaching effective blank levels first. The significance of adding F-113 to the existing suite of measurable oceanic transient tracers rests in the possibility of age-dating water masses by their (F-113/F-11) ratio with near annual resolution for the period since 1977.

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Fleagle, R.G., N.A. Bond, and W.A. Nuss (1988): Atmosphere-ocean interaction in mid-latitude storms. *Meteorol. Atmos. Phys., 38,* 50-63.

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Roach, A.T., J.D. Schumacher, and P.J. Stabeno (1987): Observations of currents, surface winds and bottom pressure in Shelikof Strait, Autumn, 1984. NOAA Tech. Memo. ERL PMEL-74, 116 pp.

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Boehlert, G.W. (1988): An approach to recruitment research in insular ecosystems. Proceedings of the IREP (OSLR) Workshop on Recruitment in Tropical Coastal Demersal Communities, Cuidad del Carmen, Campeche, Mexico, April 1986, A. Yanez-Arancibia, D. Pauly, and J. Czirke (eds.), IOC Workshop Report No. 44, Supplement, 33-44.

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GLOSSARY OF ACRONYMS

ADCP: Acoustic Doppler Current Profiler
AID: Agency for International Development
AOML: Atlantic Oceanographic and Meteorological Laboratory
APEX: Arctic Polynya Experiment
ARGOS: French satellite used to telemeter data to shore stations (not an acronym)
ASG: Administrative Support Group
ATLAS: Automated Temperature Line Acquisition System
CIRES: Cooperative Institute for Research in Environmental Sciences
CIMRS: Cooperative Institute for Marine Resources Studies
COADS: Comprehensive Ocean-Atmosphere Data Set
CSG: Computer Support Group
CTD: Conductivity, Temperature, Depth
EDD: Engineering Development Division
ENSO: El Niño-Southern Oscillation
EOF: Empirical Orthogonal Function
EPOCS: Equatorial Pacific Ocean Climate Studies
ERL: Environmental Research Laboratories
FAST: Flow Actuated Sediment Trap
FGGE: First GARP Global Experiment
FOCAL: French Program Ocean-Climat Atlantique Equatorial
FOCI: Fisheries-Oceanography Coordinated Initiative
FOCUS: Fisheries Oceanography Cooperative Users System
FOX: Fishery-Oceanography Experiment
GARP: Global Atmospheric Research Program
GFDL: Geophysical Fluid Dynamics Laboratory
GMCC: Geophysical Monitoring for Climatic Change Division, ERL
GOES: Geostationary Operational Environmental Satellite
HMSC: Hatfield Marine Science Center
IAMAP/IAPSO: International Association of Meterology and Atmospheric Physics/ International Association for the Physical Sciences of the Ocean
IGOSS: International Global Ocean Services System
IOC: International Oceanographic Commission
IRIS: International Recruitment Investigations in the Subarctic
ITCZ: Intertropical Convergence Zone
JIC: Navy/NOAA Joint Ice Center
JIMAR: Joint Institute for Marine and Atmospheric Research
JISAO: Joint Institute for the Study of Atmosphere and Ocean
L-RERP: Long-Range Effects Research Program
MARD: Marine Assessment Research Division
MIZ: Marginal Ice Zone

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MIZEX:	Marginal Ice Zone Experiment
MMS:	Minerals Management Service, U.S. Dept. of Interior
MRRD:	Marine Resources Research Division
MSRD:	Marine Services Research Division
NCAR:	National Center for Atmospheric Research
NESDIS:	National Environmental Satellite, Data, and Information Service
NIC:	NOAA Information Center
NMC:	National Meteorological Center
NMFS:	National Marine Fisheries Service
NOAA:	National Oceanic and Atmospheric Administration
NOS:	National Ocean Service
NORPAX:	North Pacific Experiment
NWAFC:	Northwest and Alaska Fisheries Center
NWS:	National Weather Service
OAR:	Oceanic and Atmospheric Research
OCRD:	Ocean Climate Research Division
PENTAFLUX:	Fifth Flux Experiment
PEQUOD:	Pacific Equatorial Ocean Dynamics
PMEL:	Pacific Marine Environmental Laboratory
Ri:	Richardson Number, a dimensionless number related to stability of stratified flow
RJE:	Remote Job Entry
SCOR:	Scientific Committee on Oceanic Research
SEABEAM:	A shipboard multi-transducer swath echo sounding system
SLAR:	Side-Looking Airborne Radar
SLEUTH:	System for Locating Eruptive Underwater Turbidity and Hydrography
SLP:	Sea Level Pressure
S^3T:	Sequentially Sampling Sediment Trap
SST:	Sea Surface Temperature
STACS:	Subtropical Atlantic Climate Study
TAG:	Trans Atlantic Geotraverse
THRUST:	Tsunami Hazard Reduction Using System Technology
TOGA:	Tropical Oceans and Global Atmosphere
TOPS:	Total Ocean Profiling System
USGS:	United States Geological Survey
VENTS:	Name of hydrothermal venting research program (not an acronym)
WEPOCS:	Western Equatorial Pacific Ocean Circulation Study
WMO:	World Meteorological Organization
XBT:	Expendable Bathythermograph

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